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FIRE PROTECTION RESEARCH AND DEVELOPMENT REQUIREMENTS ANALYSIS FOR USAF SPACE SYSTEMS AND GROUND SUPPORT FACILITIES
VOLUME I - FIRE PROTECTION OPERATIONAL REQUIREMENTS ANALYSIS

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This technical report has been reviewed and is approved for publication.

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13. ABSTRACT *(Maximum 200 words)*

This technical effort justified fire protection research and development (R&D) requirements that are unique to the fire departments operating at Cape Canaveral Air Station (CCAS), Florida, and Vandenberg Air Force Base (VAFB), California. Operational uniqueness was established by the mission requirement of these fire departments to conduct fire suppression, rescue and/or hazardous material (HAZMAT) emergency response operations involving the extremely toxic and explosive hypergolic propellants used in space lift vehicles and satellites. The technical approach employed an operational hazard analysis of space launch and payload processing facilities and operations to determine emergency response environments. The final products are a technical report, five (5) draft Operational Requirements Documents (ORDs), a draft Purchase Description (PD), and a draft HAZMAT Emergency Response Plan for civilian contractors.

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PREFACE

This report was prepared by Aerosafe International, 3033 Richmond Parkway, Richmond, California, for the Wright Laboratory, Infrastructure Technology Section, Fire Research Group (WL/FIVCF), 139 Barnes Drive, Suite 2, Tyndall Air Force Base, Florida 32403-5323. The work was accomplished under Air Force Development Test Center Contract Number F08635-93-C-0042.

The final report presents the results of an analysis to determine fire protection Research and Development (R&D) requirements that are unique to the fire departments operating at Cape Canaveral Air Station (CCAS), Florida, and Vandenberg Air Force Base (VAFB), California. The operational uniqueness is established by virtue of the CCAS and VAFB fire departments' requirement to conduct fire suppression, rescue and/or hazardous material (HAZMAT) response operations involving the unique hypergolic propellants used in lift vehicles and satellites.

The basis of this technical report was an operational hazard analysis of the space launch and payload processing operations to which the fire department must be ready to provide emergency response at Cape Canaveral Air Station (CCAS), FL and at Vandenberg Air Force Base (VAFB), Ca. The analysis required detailed information on fire department policies, procedures and tactics, operational fire fighting apparatus and equipment for space launch facility support, as well as details of installed facility fire protection systems. Additionally, the analysis required site access to the unique payload and launch vehicle processing facilities at CCAS and VAFB to determine infrastructure parameters that influence fire protection systems and operational procedures.

To provide the authors with a full understanding of the propellant-related hazardous operations that are conducted in/on CCAS and VAFB facilities, extensive discussions were conducted with launch support and payload processing contractors, as well as range and pad safety personnel. This information was used to generate hazard scenarios for operations where accidental releases may occur. Space launch-unique operational fire department missions and capabilities were then based on hazard analysis results. Finally, required capabilities were used to identify and validate fire protection research and development (R&D) requirements that are based on firm, space launch operational needs.

The authors wish to express their sincere appreciation to the many individuals who contributed the support and success of this technical effort. They made it possible to gather the extensive data base cited above that was essential to accuracy and validity of the report's findings and conclusions.

Our data collection and operational assessment of Cape Canaveral Air Station, FL, launch support operations and facilities was hosted and supported by the Patrick Air Force Base Fire Chief, Mr. Tom Stevens, and his deputies, Mr. Joseph Giantonio and Chief Master Sergeant (Selectee) Raymond Guerero. Chief Stevens and his staff shouldered a large burden of additional administrative and coordination actions associated with our site visits and analysis results. Without his support and assistance, this effort would not succeeded in fully identifying and supporting space launch fire protection R&D requirements. Mr. John Kinstle of the 45th Space Wing Range Safety Office also provided invaluable support to this technical effort.

The Cape Canaveral Air Station Fire Department is a contractor-operated organization, and a part of Johnson Controls Launch Base Support Contract. Fire Chief Charles Richardson, and his successor, Chief Norbert Kuhman, extended the full courtesies and support of their organization, and the value of their operational experience in the review of our findings and recommendations.

In particular, we wish to acknowledge the support of CCAS Assistant Fire Chief for Fire Prevention, Mr. Henry Pankow. He organized and led our many site visits to the CCAS launch facilities and put us in contact with the operational and Pad Safety professionals needed for our understanding of fire protection hazards and operational requirements.

At Vandenberg AFB, we were provided strong support from Fire Chief Art Hill and his successor, Chief Paul Giles. Our VAFB site visits were organized and hosted by Mr. Ronald Colegrove, from the 30th Space Wing System Safety Office. Mr. Colegrove was an exceptionally cordial host and provided the Wright Laboratory team with access to the VAFB launch and payload processing support contractor community for analysis data base information.

We also wish to acknowledge the dedication and support of Master Sergeant Mark Captain, from the Fire Protection Office at Headquarters Air Force Space Command. Sergeant Captain was a valuable member of our analysis review and validation team. He is the Project Officer for major command staffing and processing of the Operational Requirements Documents (ORDs) that resulted from this technical effort.

Mr. Ross J. Utt, Mr. E. Raymond Lake and Dr. John H. Storm were the Aerosafe International Principal Investigators. The WL/FIVCF Project Officer was Mr. George F. Hall. The analysis was conducted from 31 March 1993 to 15 April 1995.

EXECUTIVE SUMMARY

A. OBJECTIVE

The objective of this analysis was to determine fire protection research and development (R&D) requirements that are unique to the fire departments operating at Cape Canaveral Air Station (CCAS), Florida, and Vandenberg Air Force Base (VAFB), California. Operational uniqueness was established by virtue of the mission requirement for these fire departments to conduct fire suppression, rescue and/or hazardous material (HAZMAT) emergency response operations involving the extremely toxic and explosive hypergolic propellants used in space lift vehicles and satellites.

B. BACKGROUND

The fire departments at CCAS and VAFB are the only two units in the USAF that must be equipped and trained to respond to accidental releases and, possibly, fires involving large quantities of highly toxic and explosive hypergolic propellants. Wright Laboratory's Infrastructure Technology Section, Fire Research Group, (WL/FIVCF), Tyndall Air Force Base, Florida, developed this analysis task to ensure that CCAS and VAFB requirements for improved fire protection technologies are defined and supported in the Civil Engineering research, development and acquisition (RD&A) process. Potential required capabilities include improved fire extinguishing agents, vehicles and equipment, as well as new technology fire and vapor detection systems and fire fighter personal protective equipment (PPE).

C. SCOPE

This research quantifies fire protection R&D requirements generated by the CCAS and VAFB fire department missions to provide suppression, rescue and fire prevention in support of United States Air Force (USAF), Department of Defense (DoD) and commercial satellite launch operations. The final products are a technical report, five (5) draft Operational Requirements Documents (ORDs), a draft purchase description (PD), and a draft HAZMAT Emergency Response Plan for civilian contractors, and two briefing packages on facility life safety requirements standards.

D. TECHNICAL APPROACH

1. The technical approach employed an operational hazard analysis of space launch and payload processing facilities and operations at the CCAS and VAFB launch sites to determine fire department emergency response environments and requirements. The mechanisms and estimated quantities of accidental releases of highly flammable, explosive and toxic hypergolic propellants were quantified.

2. The required fire department operational capabilities for effective fire suppression and rescue emergency response were determined. Inventory fire department agents, vehicles and fire prevention systems were mapped to the identified required capabilities. R&D requirements were established for required capabilities that are not available from inventory assets or off-the-shelf technologies.

3. All analysis findings and recommendations were validated by the Air Force Space Command fire protection community and reviewed by the CCAS and VAFB safety offices.

E. HYPERGOLIC PROPELLANT HAZARD ANALYSIS CONCLUSIONS

1. The probability of an accidental release of hypergolic chemicals at CCAS or VAFB is low. This low release incidence estimate is founded on the space launch community's strictly-enforced system safety programs, the use of strictly-controlled propellant transfer operations procedures, and effective maintenance of propellant storage and handling facilities and equipment.

2. Credible release quantities of hydrazine fuels or oxidizer that are likely to result from accidents, transfer system material failures or human error range from 0.1 to 400 gallons.

3. A catastrophic propellant release was judged to be possible, but highly improbable. Releases above 400 gallons were not considered by this technical effort. A very large propellant release would generate requirements for large additional amounts of fire fighter manpower, agent and equipment resources. It would not generate the requirement for unique fire department technologies. The unique fire department operational requirements identified by this analysis for releases up to 400 gallons apply equally to larger events.

4. CCAS and VAFB fire fighters cannot safely conduct suppression and/or rescue operations in the vicinity of the toxic vapors and combustion products associated a hypergolic propellant vapor release and fire. Current fire fighter reflectorized ensembles do not provide the full encapsulation required by OSHA for protection against propellant toxic vapors. Inventory fully-encapsulated fire fighter HAZMAT suits will melt in the proximity of a fire.

5. Many different civilian contractor companies are involved in hypergolic propellant transfer operations or have employees who may be nearby an accidental release. Therefore, consistent OSHA-compliant hazardous chemical release emergency response plans, procedures and training are required to ensure the life safety of personnel.

6. CCAS and VAFB fire fighters urgently need live fire-validated extinguishing agent performance data to plan for safe and effective hydrazine and N_2O_4-enriched fire fighting and rescue operations.

7. Personnel working inside elevated launch tower clean rooms or who may be working on launch towers in the proximity of other hazardous systems/operations require a direct, rapid, emergency egress system from the elevation where the hazardous operation takes place to the ground, below.

F. FIRE DEPARTMENT REQUIREMENTS FOR INCREASED OPERATIONAL CAPABILITIES

1. A draft Operational Requirements Document (ORD) was prepared and delivered to HQ AFSPC for the development, testing and acquisition of each fire protection technology requiring R&D. Required capabilities were prioritized by the AFSPC fire protection community, as follows:

a. A combined fire fighter/HAZMAT protective ensemble with body cooling for sustained fire fighting and rescue operations in a dual threat hypergolic propellant fire and toxic vapor environment.

b. Hydrazine vapor detection capable of incipient leak identification in the 1 - 25 parts per million (ppm) concentration range.

c. An additive to water, foam and dry chemical fire extinguishing agents that produces a visible flame and/or smoke when applied to a hydrazine fire.

d. False-alarm immune hydrazine flame detection.

e. Optimization of fire extinguishment parameters and capabilities for current technology agents, such as water, dry chemicals and foams (including acrylic-modified foams) based on large fire (400 gallons/5,000 square feet) experiments.

2. Two operational requirements that are not within current inventory capabilities, but can be obtained from off-the-shelf technologies also were validated:

a. Life safety upgrades in MST launch tower clean room facilities, to include means of egress from high elevation hazard areas. A draft purchase description (PD) for a portable emergency escape chute system was delivered to HQ AFSPC.

b. OSHA-compliant, launch tower emergency response plans and procedures for civilian contractors and their employees. A draft contractor HAZMAT Emergency Response Plan was delivered to HQ AFSPC.

G. RECOMMENDATIONS

1. Headquarters Air Force Space Command should:

a. Approve the five ORDs for enhanced fire protection capabilities at space launch support facilities.

b. Submit these ORDs for Air Force-wide review and validation, according to the procedures contained in AFI 10-601, *Mission Needs and Operational Requirements Guidance and Procedures*, 31 May 1994.

c. Advocate joint sponsorship of the ORD for the combined fire fighter/HAZMAT protective ensemble with body cooling to the Combat Air Forces (CAF) and joint services.

2. Commanders at CCAS and VAFB should review the draft HAZMAT emergency response plan and the draft purchase description for a launch tower emergency escape chute system for potential use as enhancements to their on-going emergency response and OSHA process safety management (PSM) programs.

H. APPLICATION

1. The flame and vapor detection technologies identified by this analysis can be applied immediately to CCAS and VAFB propellant storage facilities and payload processing clean rooms. The chemical luminescence additive to permit the visible identification of hydrazine fires can be used immediately by the CCAS and VAFB fire departments.

2. The combined fire fighter/HAZMAT protective ensemble with body cooling is applicable immediately to all Air Force, DOD, NASA, DOE and other Government personnel who require the use of fully-encapsulated equipment for toxic chemical and/or fire fighting protection.

3. Once fire fighting agent suppression effectiveness parameters for large scale hypergolic propellant fires are identified by R&D, this information can be used by CCAS and VAFB fire departments to develop tactics, procedures, apparatus and equipment for optimum fire extinguishment response to hypergolic fuel and oxidizer releases and fires.

I. BENEFITS

The potential benefits from the identified R&D technologies include:

- More rapid and reliable detection of hydrazine vapor releases and fires,
- Increased life safety of personnel involved in hypergolic propellant hazardous operations and in emergency response to accidental HAZMAT releases,
- The capability to extinguish hypergolic propellant fires in a toxic vapor environment,
- A significant increase in fire fighter operational sustainability while wearing a protective ensemble, and,
- More effective and safer extinguishment of hypergolic propellant fires.

J. TRANSFERABILITY OF TECHNOLOGY

1. Potential non-DOD users of flame and vapor detection technologies, of the chemical luminescence additive, and of optimum fire extinguishing agents include chemical producers of hydrazines and industrial fire brigades in facilities or plants that use and store hydrazines.

2. The technologies associated with the combined fire fighter/HAZMAT protective ensemble with body cooling are transferable to all fire department and commercial organizations that are involved in processes that require employees to be protected against the effects of toxic chemicals and/or fires involving HAZMATs. Fundamentally, the ensemble technologies are universally transferable, worldwide.

3. All technologies identified for enhanced fire department support of space launch operations and facilities are transferable to foreign and commercial organizations with similar hazardous processes, facilities and missions.

SECTION I

INTRODUCTION

A. OBJECTIVE

1. The objective of this analysis was to determine fire protection research and development (R&D) requirements that are unique to the fire departments operating at Cape Canaveral Air Station (CCAS), Florida, and Vandenberg Air Force Base (VAFB), California.

2. Operational uniqueness was established by virtue of the mission requirement for these fire departments to conduct fire suppression, rescue and/or hazardous material (HAZMAT) emergency response operations involving the extremely toxic and explosive hypergolic propellants used in space lift vehicles and satellites.

B. BACKGROUND

1. The fire departments at CCAS and VAFB are the only two units in the USAF that must be equipped and trained to respond to accidental releases and, possibly, fires involving large quantities of highly toxic and explosive hypergolic propellants. Their mission is to provide structural, crash, rescue, and fire prevention capabilities for the launch support facilities, space launch vehicles, payloads, and hazardous propellant storage and transfer facilities involved in United States Air Force (USAF, DoD and commercial satellite launch operations.

2. Hypergolic chemicals are extremely dangerous to fire fighting and rescue operations:

a. The fuels, Anhydrous Hydrazine, AH (N_2H_4), and its derivatives, monomeythlhydrazine, MMH (CH_6N_2), unsymmetrical dimethylhydrazine UDMH ($C_2H_8N_2$) and Aerozine 50 (A-50), a 50:50 percent mixture of AH and UDMH, spontaneously and violently react when contacted with oxides, such as rust, dust and debris, flame or spark.

b. The oxidizer, nitrogen tetroxide (N_2O_4) is not combustible, but will enrich a hydrocarbon fuel fire producing a more violent flame and much higher temperatures.

c. Both fuels and oxidizers are extremely toxic by inhalation and skin contact routes.

3. In 1990, the Engineering and Services Space Liaison Group was chartered to determine the roles and missions of Civil Engineer organizations in the newly-formed Air Force Space Command (AFSPC). The group explicitly stated the requirement for research in Space Command-unique technology areas: ***"R&D in the Fire Protection area is mandatory - a link we have to pursue....combating rocket fuel fires and crash rescue for space lift support are immediate problems."***

4. Wright Laboratory's Infrastructure Technology Section, Fire Research Group, (WL/FIVCF), Tyndall Air Force Base, Florida, developed this analysis task to ensure that CCAS and VAFB requirements for improved fire protection technologies are defined and supported in the Civil Engineering research, development and acquisition (RD&A) process. Potential required capabilities include improved fire extinguishing agents, vehicles and equipment, as well as new technology fire and vapor detection systems, and fire fighter personal protective equipment (PPE).

C. SCOPE

1. This research quantifies fire protection R&D requirements generated by the CCAS and VAFB fire department missions to provide suppression, rescue and fire prevention in support of United States Air Force (USAF), Department of Defense (DoD) and commercial satellite launch operations. The final products are a technical report, five (5) draft Operational Requirements Documents (ORDs), a draft purchase description (PD), a draft HAZMAT Emergency Response Plan for civilian contractors, and two briefing packages on facility life safety requirements standards.

2. The ORDs and the PD identify required increases in fire protection capabilities that are justified by this analysis and operationally-validated by the AFSPC fire protection community. ORDs identify fire protection and prevention needs that cannot be met from off-the-shelf-technologies and, therefore, require research, development and acquisition.

3. The PD provides procurement information for the local purchase of hardware to improve launch tower life safety. The HAZMAT Plan is for CCAS and VAFB support contractor use to enable full compliance with OSHA requirements for worker safety in the event of an accidental release of a hypergolic chemical.

D. DOCUMENT ORGANIZATION

1. This final technical report is organized in two volumes. Volume I contains the space launch facility fire protection operational requirements analysis and results.

Volume II contains operational requirements documentation and data on the storage and delivery of hypergolic commodities during the various stages of launch vehicle and payload processing servicing and support.

2. In Volume I, Section II describes typical launch facilities that require fire prevention technical support and fire-rescue operational response from the CCAS and VAFB fire departments. Section III details the technical approached used by this analysis to determine CCAS and VAFB R&D requirements based on validated operational needs. In Section IV, the chemical and combustion properties of hypergolic propellants are summarized. Section V describes the methodology used to determine the knowledge base of unique fire department operational requirements that result from the CCAS/VAFB missions to support the Air Force's space launch programs. Five specific operational requirements are identified.

3. Volume I, Section VI, provides descriptions and capacities of the mobile trailers and portable containers used to store and transport hypergolic propellants on CCAS and VAFB. Similarly, in Section VII, descriptions of fixed, bulk propellant storage facilities are provided. An explanation of hypergolic propellant flow charts is provided in Section VIII. Flow charts define the receiving, storage, handling, distribution and end use paths of each hypergolic propellant used on CCAS and VAFB.

4. In Volume I, Section IX describes the hazard analysis performed on CCAS and VAFB to identify the hypergolic propellant release scenarios and mechanisms that could require fire department emergency response. Quantities of hypergolic propellant associated with each release mechanism are computed in Section X. Hazard analysis results and accidental release quantities are used as the basis for determining hypergolic propellant-related operational requirements for improved fire department capabilities in Section XI. Seven operational requirements are identified for capabilities that exceed inventory assets. Five require R&D, and two can be obtained from off-the-shelf sources. The summary, conclusions and recommendations of this technical effort are detailed in Section XII.

5. In Volume II, Appendix A - Appendix E contain draft Operational Requirements Documents (ORDs) for mission-essential capabilities that cannot be met from off-the-shelf technologies. Appendix F contains a draft purchase description for a launch tower emergency escape chute system and associated vendor product information. In Appendix G, a draft HAZMAT Emergency Response Plan for CCAS and VAFB contractor use is provided.

6. Volume II also contains flow charts that detail the storage, transportation and end-use distribution of hypergolic propellants on CCAS and VAFB. They are organized by product, by container size and by end-use destination to an Air Force launch pad or payload processing facility. The flow charts depict the complete range of potential accidental release hazards caused by propellant transfer or transportation incidents. Appendix H contains CCAS flow charts, and Appendix I contains flow charts for VAFB.

7. Appendix J in Volume II contains a briefing package entitled *45th Space Wing Launch Site Fire Protection & Life Safety Requirements Analysis*. Appendix K contains a briefing package entitled *Standards Compendium, 45th Space Wing Launch Site Fire Protection & Life Safety Requirements Analysis*.

SECTION II

SPACE LAUNCH FACILITY OVERVIEW

A. INTRODUCTION

1. United States space launch operations are conducted at CCAS and VAFB. Payloads and lift vehicles are assembled and processed for launch in a wide range of very unique facilities.

2. Space launch facilities have been tailored to the specific launch vehicle they must support. At CCAS and VAFB, three launch systems are used:

- The Atlas booster with Centaur upper stage.
- The Delta IV booster.
- The Titan IV booster with Centaur upper stage.

3. Delta and Titan lift vehicles are fueled with hypergolic propellants during the final processing operations conducted prior to launch.

a. Fuel and oxidizer for the Delta second stage are delivered from the bulk storage areas to the launch site in 2,500-gallon liquid tankers. Propellants are transferred directly from the tankers to the launch vehicle.

b. Titan launch sites feature fuel and oxidizer holding areas sufficient in size to support a single launch operation. Propellants are delivered from the main bulk storage areas to the launch site in 2,500-gallon liquid tankers at VAFB, and by either 2,500-gallon tankers or 10,000-gallon rail cars at CCAS. Fuel and oxidizer for the Titan first and second stages are pumped from each holding area to the launch site umbilical tower (UT) by fixed distribution piping. Oxidizer is also pumped to the thrust vector control (TVC) system tanks that are strapped to each Titan solid rocket motor booster.

4. Payload processing facilities are located in ground-level facilities and in elevated launch tower clean rooms.

a. Satellite reaction control systems (RCS) can be fueled in ground level facilities. The fueled satellite is then transported to the launch site and mated with the booster system.

b. Payloads also can be fueled in the launch tower clean room after mating.

c. Centaur RCSs are fueled in launch tower clean rooms after mating with the booster second stage.

5. CCAS and VAFB lift vehicle and payload processing facilities are, essentially, equal in their impact on fire department support requirements.

a. The purpose of this technical effort is to identify fire department operational requirements generated by hazardous operations involving hypergolic propellants, and to document required capabilities. Fire department emergency response is generated by the accidental release of fuels and oxidizer during payload and launch vehicle support operations.

b. In this research, it was established that the differences between CCAS and VAFB launch facilities for the same booster or satellite system do not account for corresponding measurable differences in fire department operational requirements.

6. Some facility differences are important to the CCAS and VAFB fire department knowledge base, and are referenced in this report. These are associated with the different bulk hypergolic propellant storage facility configurations found at the two bases. Typical differences involve different storage tank sizes and storage area site layouts. These differences are detailed in Section VII.

B. TYPICAL LAUNCH SITE FACILITIES

Figures II-1 to II-11 depict typical Atlas, Delta IV and Titan IV launch facilities and lift vehicles at CCAS locations. Specific descriptions are provided by the figure titles. VAFB facilities are equivalent to those depicted.

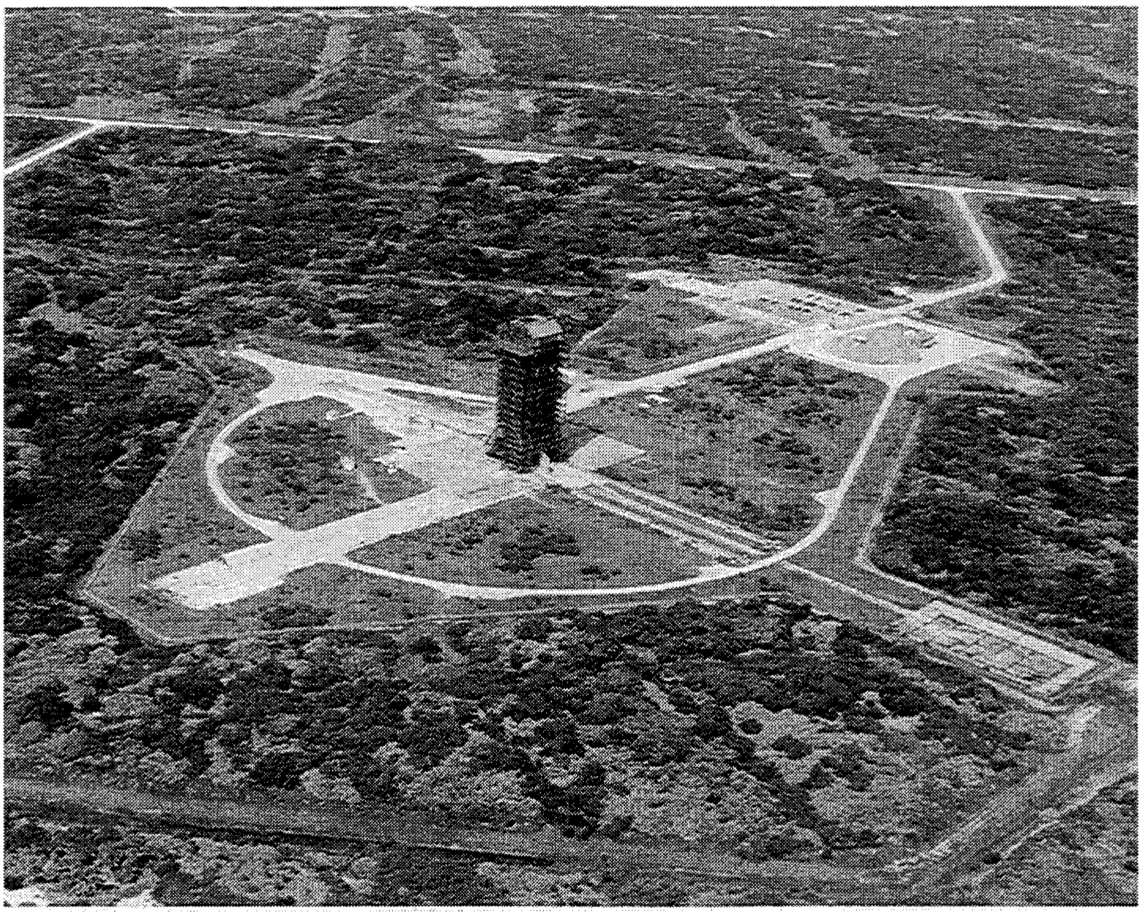


Figure II-1. Atlas Launch Complex.

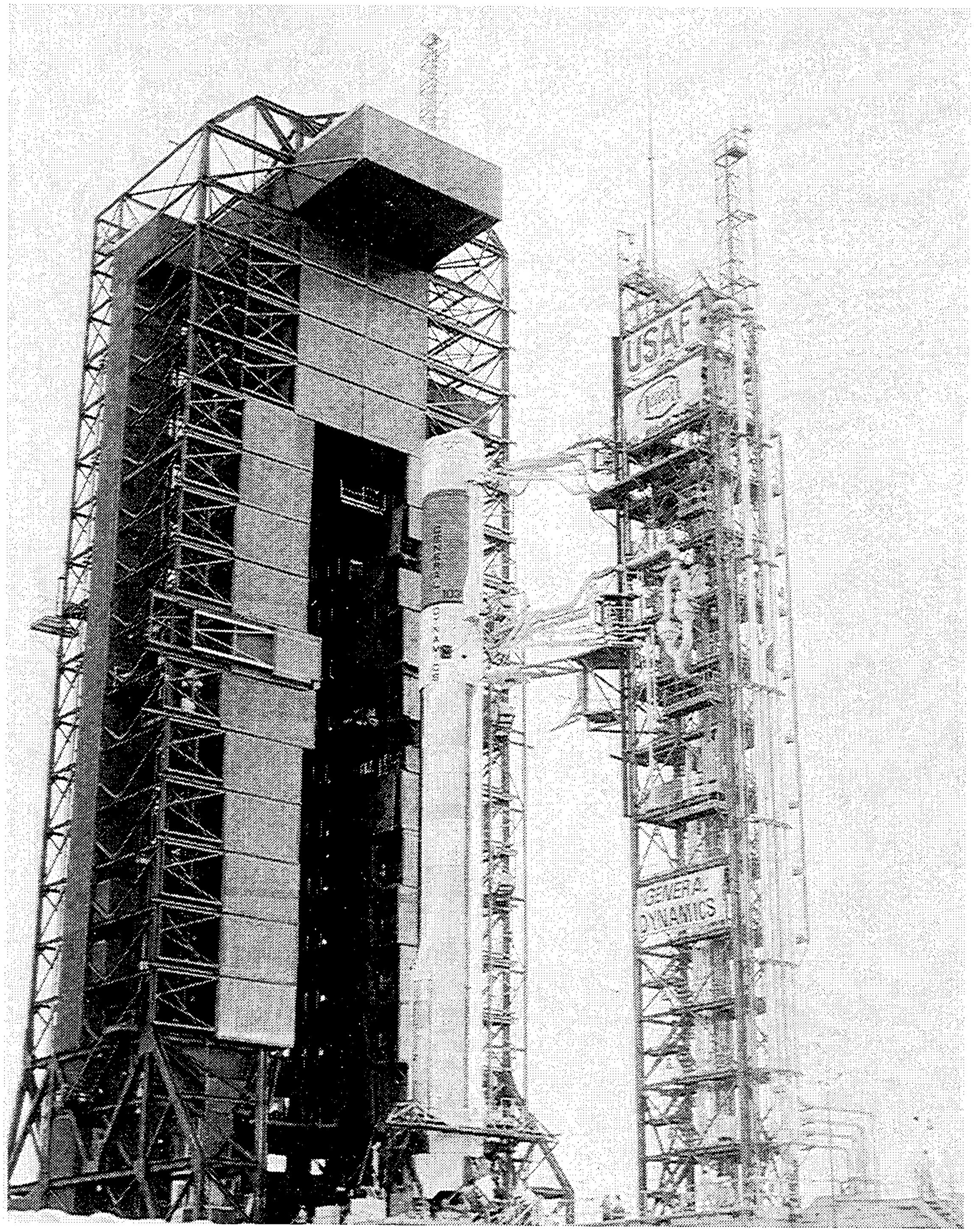


Figure II-2. Atlas Launch Complex. Left To Right: Mobile Service Tower (MST), Atlas Launch Vehicle, and Umbilical Tower UT.

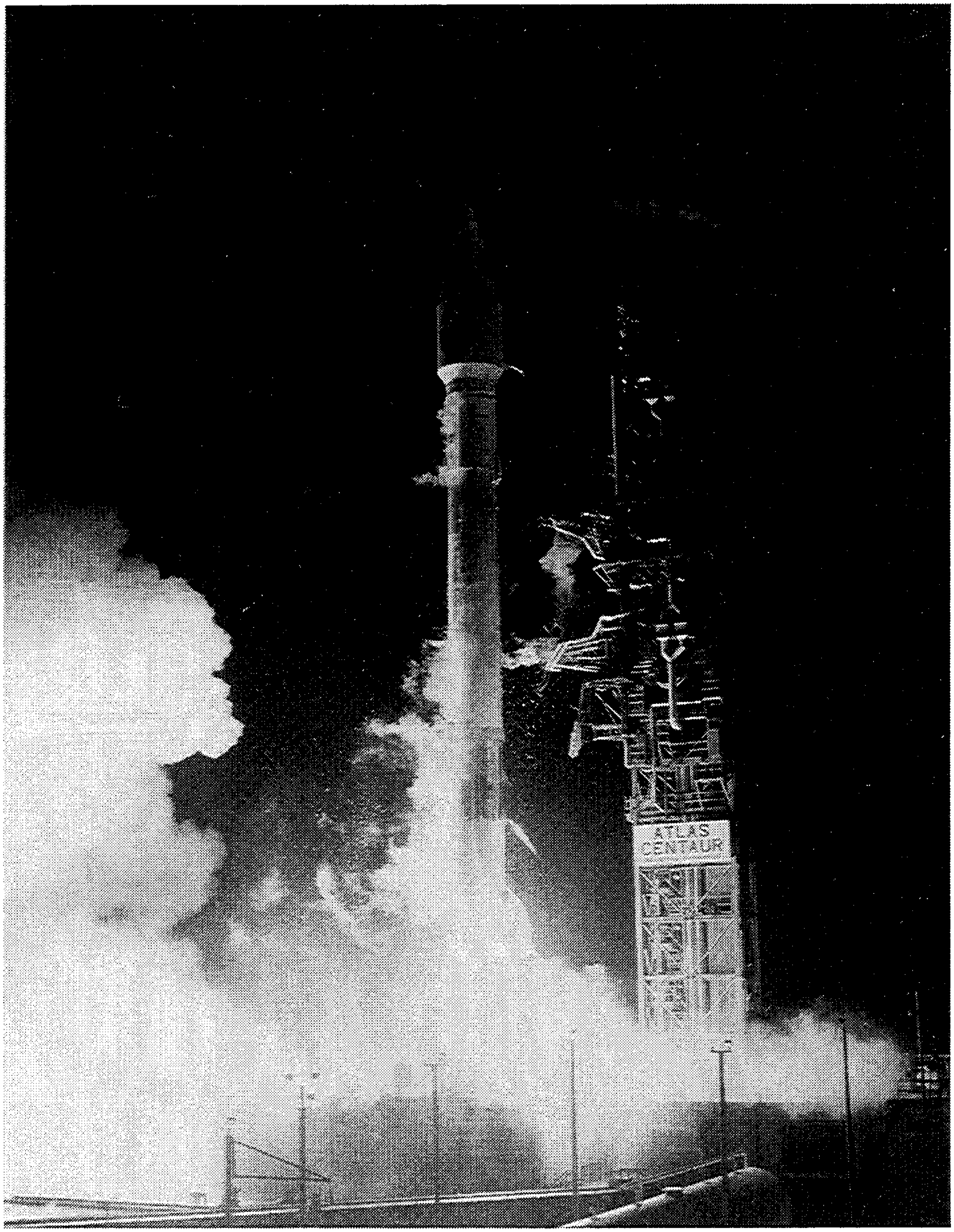


Figure II-3. Atlas Centaur Lift-Off.

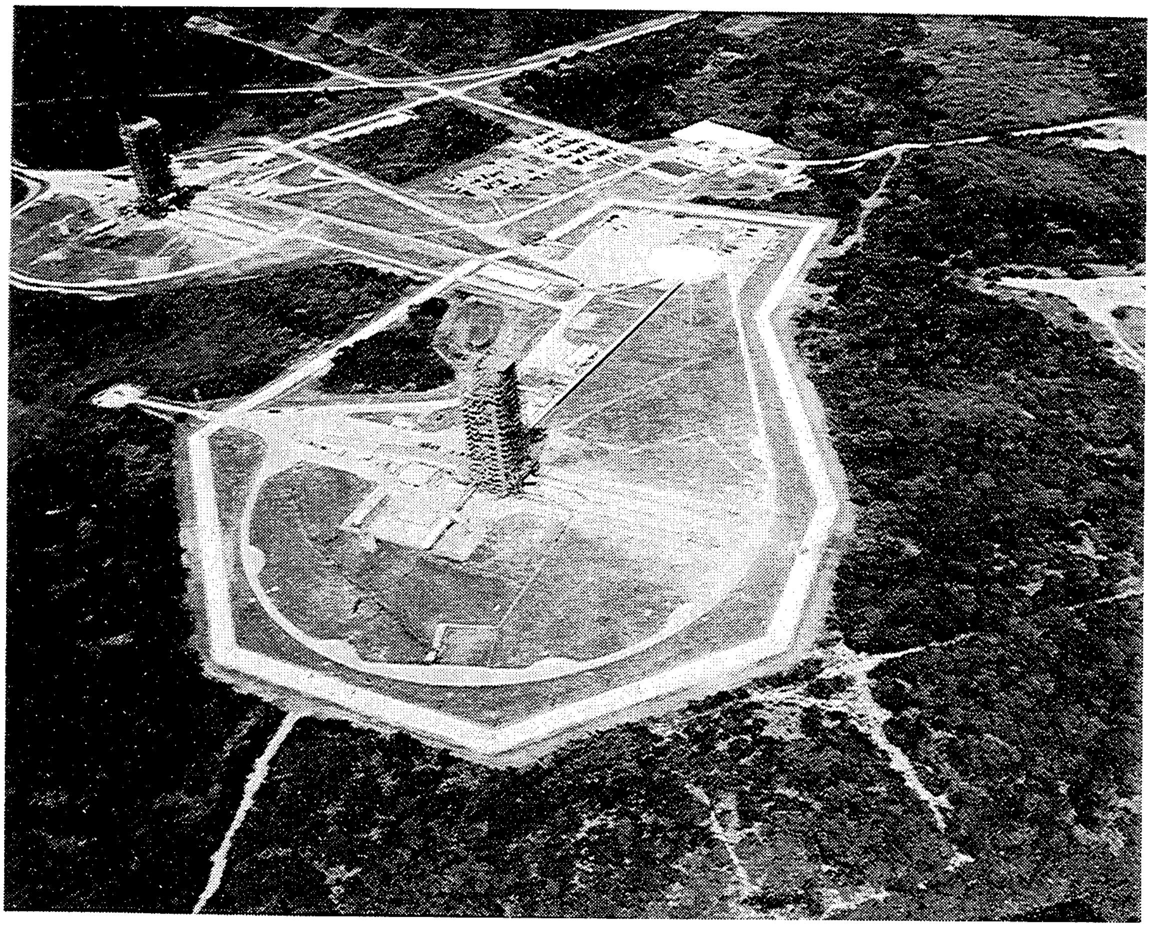


Figure II-4. Delta IV Launch Complex.

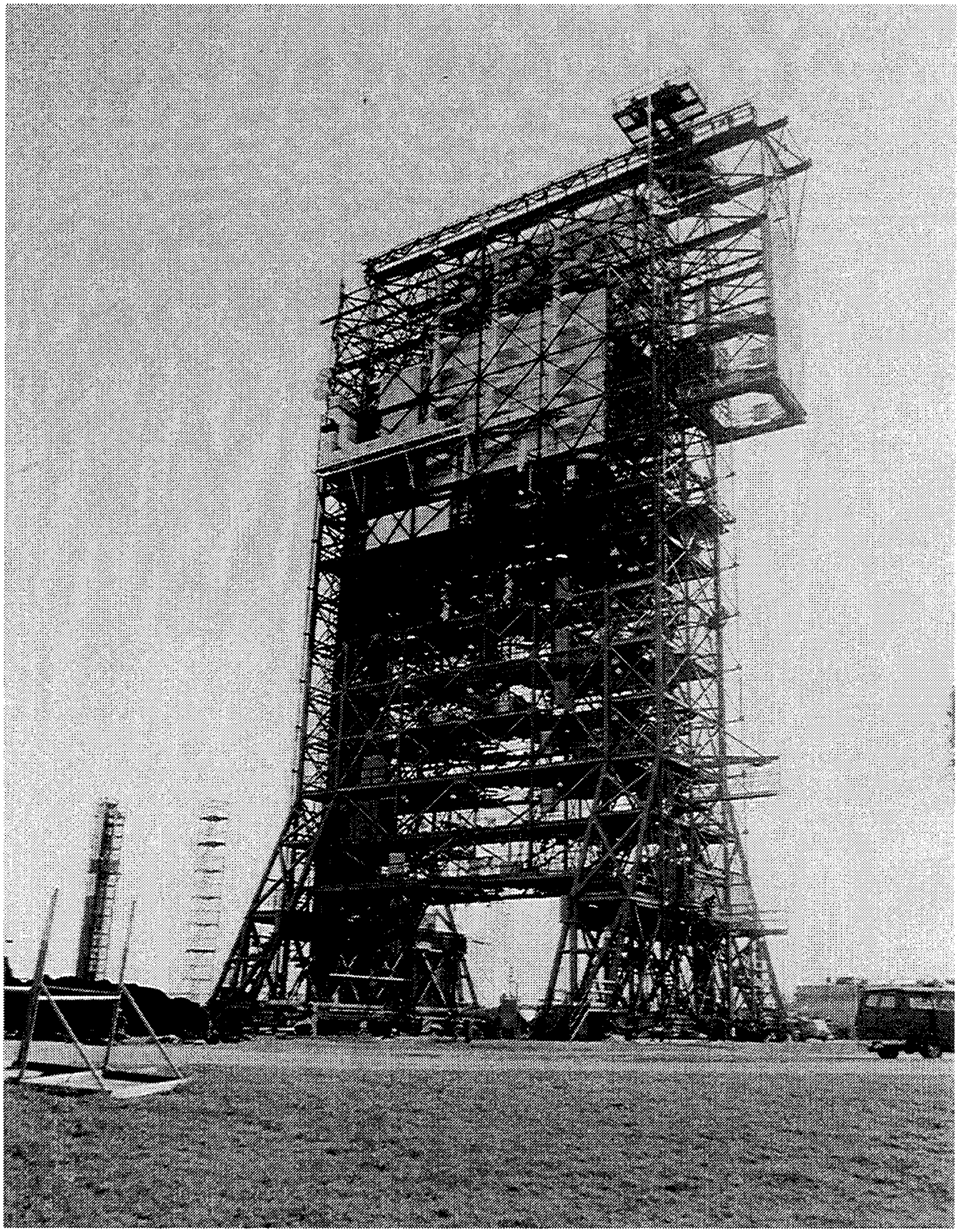


Figure II-5. Delta IV Mobile Service Tower (MST).

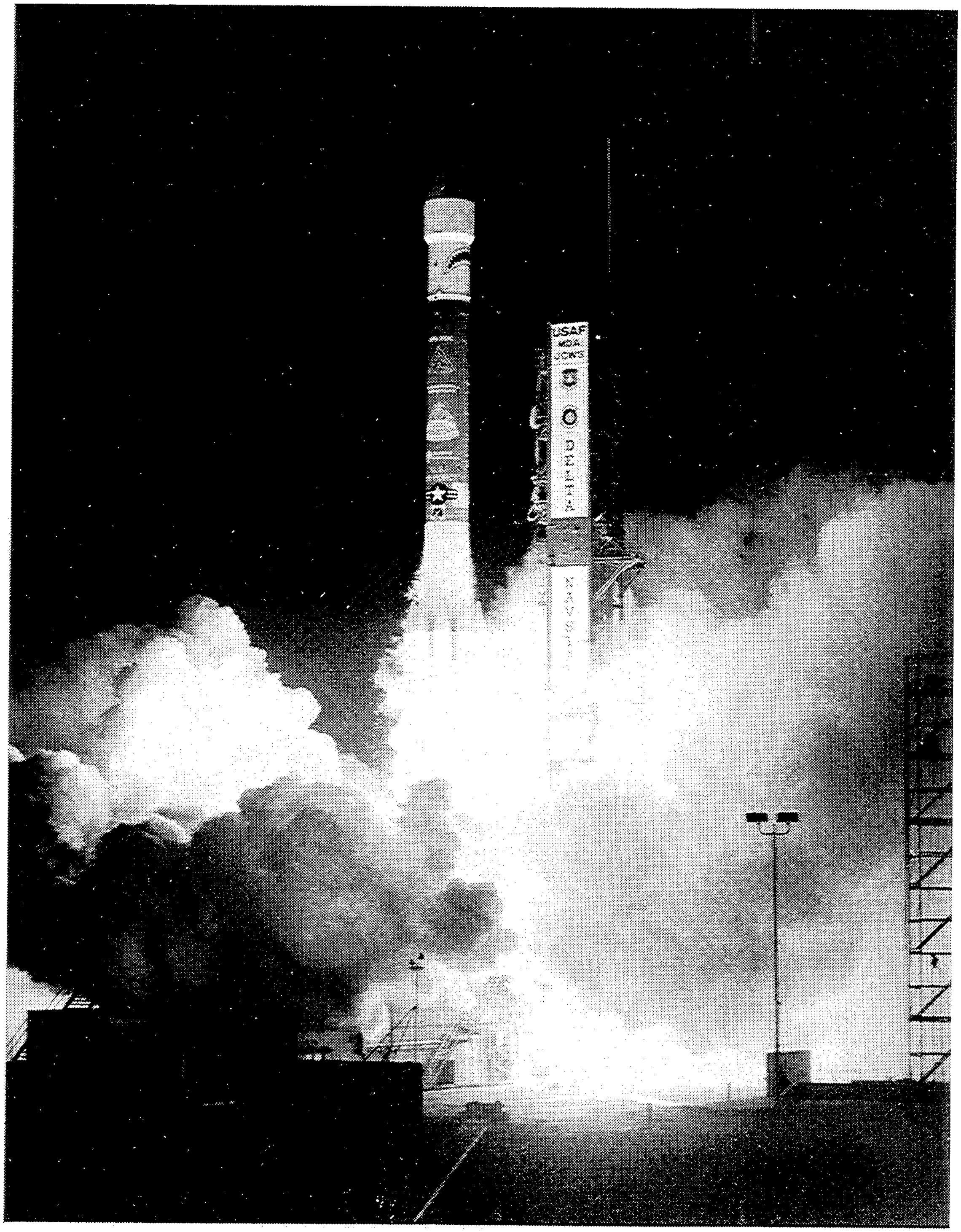


Figure II-6. Delta IV Lift-Off. Left To Right: Launch Vehicle and Umbilical Tower (UT).

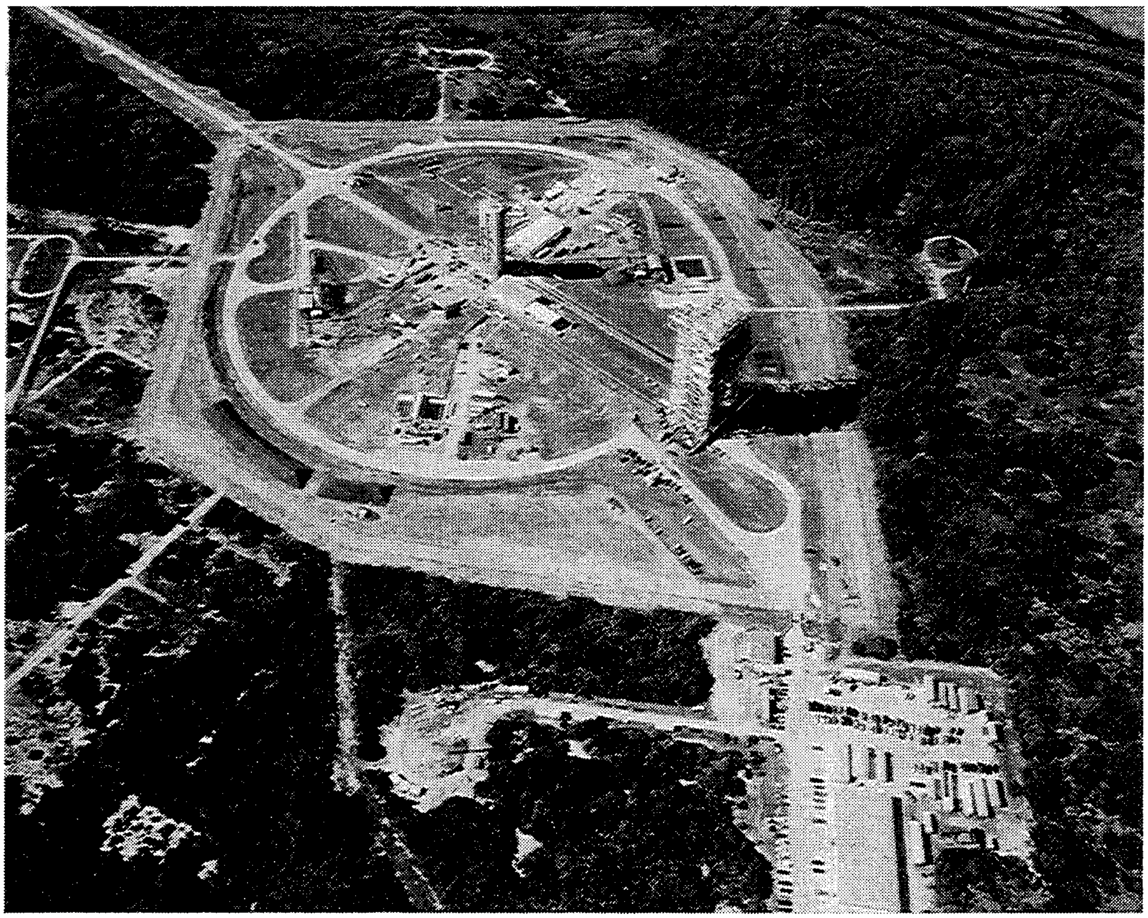


Figure II-7. Titan IV Launch Complex.

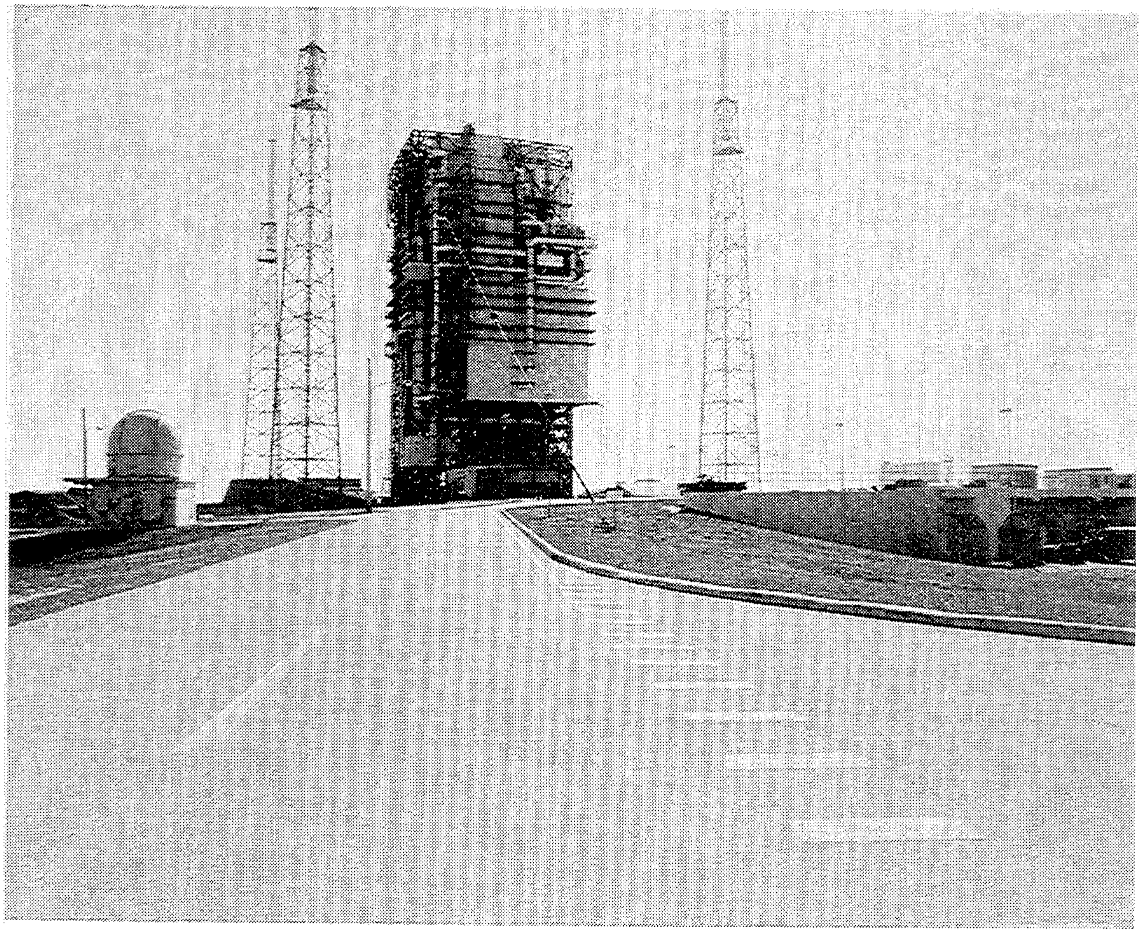


Figure II-8. Titan IV Mobile Service Tower (MST).

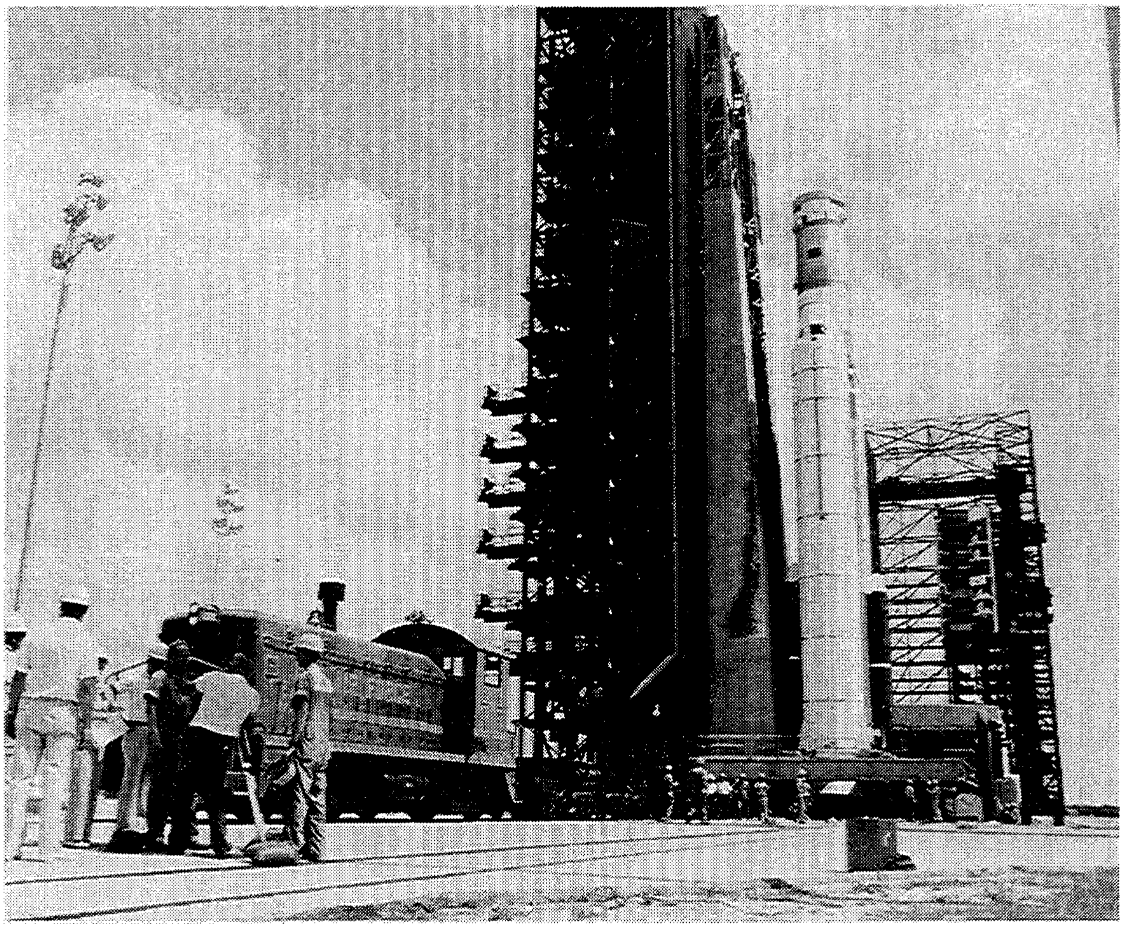


Figure II-9. Titan IV Launch Complex. Left to Right: Umbilical Tower (UT), Umbilical Mast, Titan IV Launch Vehicle, and Mobile Service Tower (MST). Note: Clean Room Interiors Are Visible At Mid-Height On The Right Side Of The MST.

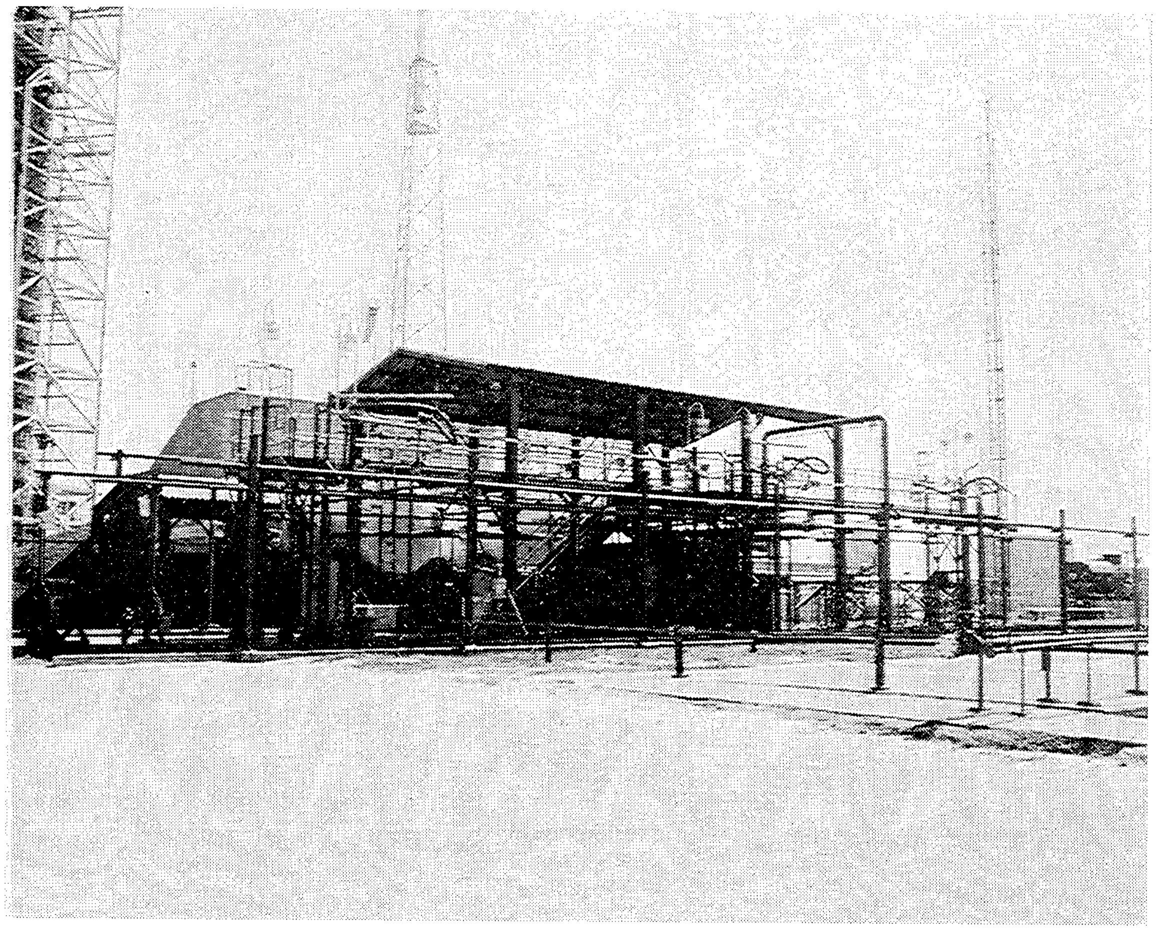


Figure II-10. Titan IV Fuel Holding Area (FHA).

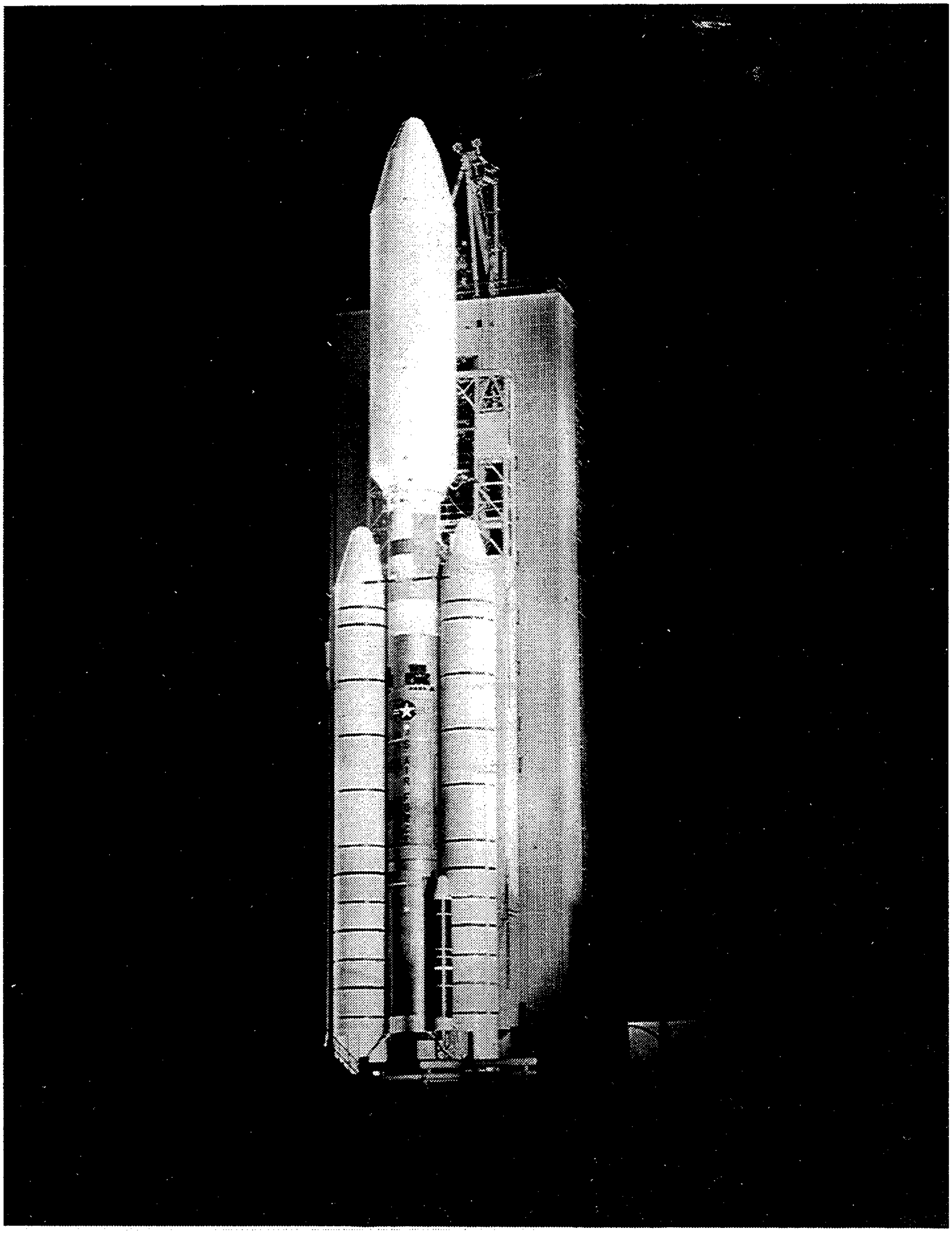


Figure II-11. Titan IV - Centaur Launch Vehicle.

SECTION III

TECHNICAL APPROACH

A. GENERAL

The technical approach followed during this research was conducted in three phases, Figure III-1.

- Phase I: April 1993 - September 1993.
- Phase II: January 1994 - June 1994.
- Phase III: October 1994 - April 1995.

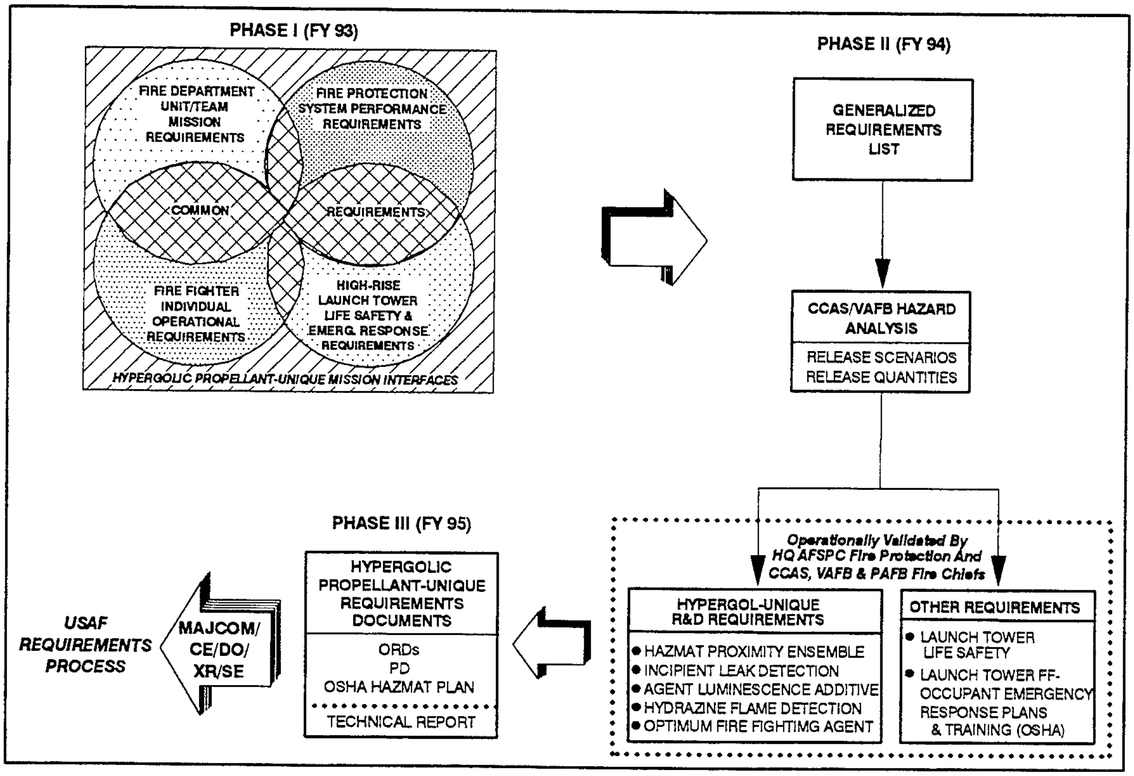


Figure III-1. Research Technical Approach.

B. PHASE I: KNOWLEDGE BASE OF CCAS AND VAFB FIRE DEPARTMENT OPERATIONS

1. CCAS and VAFB fire departments, launch support and payload processing organizations and facilities were visited to determine fire protection operations that are unique to the AFSPC mission. Base visits consisted of tours of launch complexes, support facilities, propellant storage areas, transfer and handling equipment. Discussions were conducted with responsible fire department and safety officials, as well as with technicians and engineers involved in lift vehicle and payload processing hazardous operations.

2. At each launch and launch support facility, the analysis team addressed infrastructure and organizational requirements from the four perspectives denoted by the four intersecting circles in the top, left quadrant of Figure III-1. Collectively, they represent the total knowledge base of fire department direct and peripheral involvement in the prevention of hypergolic propellant fires and in emergency response operations to accidental releases. Hazard scenarios were assumed to include hypergolic propellant explosions and fires in a toxic vapor environment, and toxic vapor releases without a fire involvement.

a. The top, left-hand circle represents the requirements of the fire department as an organization to prevent and mitigate accidental releases of propellants and to conduct fire suppression and rescue operations in the event of an accidental release. The CCAS and VAFB fire departments are organized and manned for two primary missions: prevention and operations.

- Prevention includes establishing standards and ensuring compliance with Air Force, DoD, National Fire Protection Association (NFPA), and OSHA standards for life safety and facility fire detection and suppression systems.
- Operations involve the execution of fire suppression and rescue operations and training involving conventional material and fuel threats, as well as hypergolic propellant fires and toxic chemical atmospheres.

b. The bottom, left-hand circle represents the operational requirements of the individual fire fighter who must train for and respond to hypergolic propellant fires and toxic chemical environments. Some basic, but crucial factors in this area include the requirement to:

- See and discern the boundaries of hypergolic fuel fires. Hydrazine fires are virtually invisible. They produce little or no visible flame and smoke.
- Understand and train to the fire suppression performance capabilities and limitations of the inventory fire fighting agents available to combat hypergolic propellant fires.
- Conduct safe, yet effective fire suppression and rescue tasks in a toxic chemical environment.
- Specify and wear the appropriate protective clothing to ensure fire fighter safety during suppression and rescue operations involving toxic hypergolic propellants.

c. Similarly, the top, right-hand circle in Figure III-1 contains installed fire protection system requirements that are unique to facilities that store hypergolic propellants or support processes involving the storage and transfer of these commodities. Facility system requirements are similar to those of the individual fire fighter. They must:

- Reliably detect propellant vapor releases and nearly invisible hydrazine fuel fires.
- Notify personnel and communications systems that an unplanned chemical release has occurred and where it has happened.
- Dispense a fire extinguishing agent in the vicinity of the hazard area.

d. The bottom right circle in Figure III-1 represents the fire protection and life safety factors associated with the unique combination of propellants and launch tower facilities found only at CCAS and VAFB.

(1) Universal Environmental Shelters (UES) are constructed on the higher levels of launch pad Mobile Service Towers (MST). They encircle the upper stages and payloads to provide protected access for final servicing, checkout, and propellant loading.

(2) Clean rooms are provided where access to payloads and/or fuel transfer ports are required and system contamination must be prevented. These facilities are located at elevations over 100 feet above ground level.

(3) These facility configurations generate special safety and emergency response conditions that are not covered in NFPA and OSHA standards regarding life safety or accidental toxic chemical releases. Areas of primary concern involving fire department responsibilities include:

- Means of egress from clean room and/or lift vehicle threat areas to safe havens at ground level.
- Coordinated and consistent emergency response procedures for contractor personnel involved in launch tower hazardous operations. These personnel may participate with the fire department as a part of the base's disaster response force (DRF) in the event of an accidental toxic propellant release and/or fire.

3. This analysis approach bounded all known interfaces between CCAS and VAFB fire department emergency response missions and the unique facility and installed system configurations that are associated with hypergolic propellants. In this manner, the definition of all significant fire department space lift operational requirements was virtually assured.

C. PHASE II: DEFINITION OF SPACE LAUNCH-UNIQUE FIRE PROTECTION RESEARCH AND DEVELOPMENT REQUIREMENTS

The block diagram of tasks conducted during Phase II are identified on the right-hand side of Figure III-1. Each element is detailed in the following paragraphs.

1. Generalized List Of Space Launch-Unique Fire Department Operational Requirements

a. The Phase I knowledge base analysis identified operational and technical parameters that define the space launch support-uniqueness of the CCAS and VAFB fire department missions. The fundamental differences between these two organizations and their counterparts is the requirement to be equipped and trained to respond to the accidental releases of large quantities of hypergolic propellants. Additionally, they must identify and enforce life safety and fire prevention standards in the very unique support facilities required to assemble and process launch vehicles and payloads. Combined, these mission factors and responsibilities yielded 5 fundamental, space support-based operational requirements:

(1) The ability for firefighters to see or otherwise visually detect hydrazine fuel fires. Hydrazines burn with a virtually colorless and smokeless flame.

(2) Facility hydrazine vapor and flame detection systems. Vapor detection in the 1 to 25 parts per million (ppm) sensitivity range is required to detect leaks in their incipient stage of development to prevent vapor-phase explosions. Should a leak occur where spontaneous ignition takes place, flame detection is required to alert area personnel of the danger and to initiate rapid emergency response.

(3) Fire fighters and facility fire suppression systems must be capable of extinguishing hydrazine-family fuel fires and oxidizer-enriched NFPA Class A (wood, paper, etc.) and Class B (liquid fuels) fires.

(4) Fire fighters must be able to conduct fire suppression and/or rescue operations in the presence of toxic, hypergolic fuel or oxidizer vapors.

(5) CCAS and VAFB fire departments must develop and enforce life safety and emergency response standards for personnel conducting hazardous operations in launch tower elevated clean rooms.

2. Hypergolic Propellant Process Hazard Analysis

a. Hazard analyses were conducted to determine the mechanisms and locations of accidents or incidents on CCAS and VAFB that would involve the release of hypergolic propellants and, consequently, trigger a fire department emergency response. The objective was to determine the magnitude and relative probability of occurrence of credible hypergolic release incidents. This information would then be used to quantify and justify required fire department operational capabilities.

b. The hazard analysis process was conducted at the minimum level of detail required to identify the critical parameters of importance to the fire department arriving at the scene of a hypergolic chemical release or fire incident. Essential data was determined by site surveys, personnel interviews, and the review of transfer and storage system operating procedures and engineering drawings. The analysis generated 9 basic incident/accident scenarios that involve both the release of propellants and fire department emergency response. For each scenario, release mechanisms, quantities and consequences (fire/no-fire) were estimated.

c. Once incident locations, release scenarios and release mechanisms were determined, propellant release quantities were estimated using actual capacities and flow rates of containers, distribution hardware and transfer equipment.

3. Fire Department Requirements For Increased Operational Capabilities

a. Fire department inventory agents, equipment and facility systems were evaluated against postulated hazard analysis accident scenarios and propellant release quantities. Five improved fire protection operational capabilities were identified that require research, development, testing and acquisition. These required operational capabilities were prioritized by the AFSPC fire protection community, as follows:

(1) A combined fire fighter/HAZMAT protective ensemble with body cooling for sustained fire fighting and rescue operations in a dual threat hypergolic propellant fire and toxic vapor environment.

(2) Hydrazine vapor detection capable of incipient leak identification in the 1 - 25 parts per million (ppm) concentration range.

(3) An additive to water, foam and dry chemical fire extinguishing agents that produces a visible flame and/or smoke when applied to a hydrazine fire.

(4) False-alarm immune hydrazine flame detection.

(5) Optimization of fire extinguishment parameters and capabilities for current technology agents, such as water, dry chemicals and foams (including acrylic-modified foams) based on large fire (400 gallons/5,000 square feet) experiments.

b. Two additional operational requirements that are not within current fire department inventory capabilities were identified via hazard analysis results and validated by AFSPC fire protection officials. Increased capabilities to meet these requirements can be obtained from off-the-shelf technologies. The operational requirements are:

(1) Life safety upgrades in MST launch tower clean room facilities, to include means of egress from high elevation hazard areas.

(2) OSHA-compliant, launch tower emergency response plans and procedures for civilian contractors and their employees.

D. PHASE III: OPERATIONAL REQUIREMENTS DOCUMENTATION

The final phase of this research is represented at the lower left quadrant of Figure III-1. The objective of Phase III is to document both the technical effort and the operational requirements that were identified by it.

1. All investigation and analyses conducted as a part of this research are documented in Volume I of this final technical report.

2. Volume II contains draft Operational Requirements Documents (ORDs) for the development, testing and acquisition of the 5 improved fire protection capabilities requiring R&D.

a. These documents were delivered to the HQ AFSPC Civil Engineer (HQ AFSPC/CE) for major air command review as potential candidates for development and acquisition.

b. The Civil Engineer will initiate the using command internal review process and develop initial operational concepts and budget estimates that support these requirements. This, generally, will be accomplished in close coordination with the Headquarters Air Force Space Command operations (DO), safety (SE) and plans (XP) communities.

c. ORDs that receive HQ AFSPC approval will be coordinated and validated by the corporate Air Force, according to the process that is identified in AFI 10-601, Mission Needs and Operational Requirements Guidance And Procedures.

3. Requirements documents for capabilities that do not require R&D also are provided in Volume II of the final technical report.

a. A draft purchase description (PD) for a portable emergency escape chute system was delivered to HQ AFSPC. This will enable local or command-level procurement of these systems, according to CCAS and VAFB operational needs and funds availability.

b. A draft, OSHA-compliant, contractor HAZMAT Emergency Response Plan also was delivered to HQ AFSPC. This document will be reviewed by the CCAS and VAFB civil engineering and safety communities for potential use by launch support contractors who have personnel that are involved in the response to accidental hypergolic propellant releases, or who may be required to evacuate their work areas as a result of such accidents.

SECTION IV

CHEMICAL AND COMBUSTION PROPERTIES OF HYPERGOLIC PROPELLANTS

A. GENERAL

1. This section provides basic information on hypergolic propellants used to fuel space lift vehicles and satellites AT CCAS and VAFB. The purpose is to identify their chemical and combustion properties in the minimum detail required for fire fighter basic knowledge during emergency response operations. Relevant physical and chemical properties of hydrazine fuels and nitrogen tetroxide, the hypergolic oxidizer, are summarized at Figure IV-1.

PROPERTY	ANHYDROUS HYDRAZINE (AH)	MONOMEYTHL-HYDRAZINE (MMH)	UNSYMMETRICAL DIMETHYL-HYDRAZINE (UDMH)	AEROZINE-50 (50% AH/50% UDMH)	NITROGEN TETROXIDE
SPECIFIC GRAVITY	1.008	0.88	0.786	0.904	1.45
VAPOR DENSITY (AIR = 1.0)	1.1	1.59	2.1	1.4	3.2
LIQUID DENSITY (LB/GAL @ 68°F)	8.415	7.334	6.6	7.54	12.1
BOILING POINT (°F)	236	189.5	146	158	70
OPEN CUP FLASH POINT (°F)	100	34	5	5	N/A
LOWER FLAMMABILITY LIMIT (% VOL AIR)	4.7	2.5	2.5	2.0	N/A
UPPER FLAMMABILITY LIMIT (% VOL AIR)	100	98	95	100	N/A
AUTO-IGNITION TEMPERATURE (°F)	435	382	482	435	N/A
NFPA RATINGS					
HEALTH	3	3	3	3	3
FLAMMABILITY	3	3	3	3	0
REACTIVITY	2	2	1	2	0
OXIDIZER	NO	NO	NO	NO	YES

Figure IV-1. Chemical and Physical Properties of Hypergolic Propellants.

2. Hypergolic propellants are liquids that spontaneously and violently react when contacted with each other. The propellants used at CCAS consist of two categories:

a. The fuels: Anhydrous Hydrazine, AH (N_2H_4), and its derivatives, Monomeythlhydrazine, MMH (CH_6N_2), Unsymmetrical Dimethylhydrazine UDMH ($C_2H_8N_2$) and Aerozine 50 (A-50), a 50:50 percent mixture of AH and UDMH.

b. The oxidizer: Nitrogen Tetroxide (N_2O_4).

c. The fuel-oxidizer reaction generally takes place in a rocket motor system to produce hot gases that are expelled through nozzles to produce the desired magnitude of thrust for launch or maneuvering purposes.

3. A-50 is used to fuel the second stage of the Delta IV booster system and in the Titan launch vehicle's Stage I and Stage II.

4. Hypergolic fuels also are used in satellite monopropellant thruster systems. The fuel, normally AH or MMH, is passed over a catalytic material surface or metal grid where the hypergolic reaction takes place.

5. The Titan IV Thrust Vector Control System (TVC) injects nitrogen tetroxide into the exhaust plume of each solid rocket motor. The N_2O_4 causes an increase in exhaust gas temperature at the point of injection. This area of temperature increase creates thrust vector imbalance that is used for launch vehicle steering purposes.

B. CHEMICAL AND PHYSICAL PROPERTIES OF HYPERGOLIC FUELS

1. Hydrazines and hydrazine derivatives are very corrosive, extremely toxic, and present serious health risks through skin contact and inhalation routes. They are classified by OSHA as suspect human carcinogens, highly toxic, skin and eye hazards, and liver, kidney, nervous system, blood and lung toxins. They are clear, water-like, liquids with a fishy odor.

2. Personnel in the vicinity of hydrazine transfer or handling operations where liquid or vapor release may occur are required by base regulation to wear the NASA-developed Self-Contained Atmospheric Protective Ensemble (SCAPE). This is a fully-encapsulated outer garment with a tethered or self-contained breathing air supply.

3. AH is slightly more dense than water, while MMH, UDMH and A-50 are less dense, so the latter three chemicals will float on water. Vapor densities, however, for all four hydrazines are greater than air, so that ground- or below ground-level ignition sources are an extreme hazard.

4. Hydrazines evaporate at about the same rate as water. Accordingly, it will take about 26 minutes for a 0.1 inch thick spill surface to evaporate. This estimate is based on using an approximate vapor release rate of 0.02 pounds per minute per square foot.

5. Hydrazines and their vapors explode on contact with strong oxidizers, such as nitrogen tetroxide, hydrogen peroxide fluorine and halogen fluorides. Additionally, they react on contact with metallic oxides, such as iron, copper, lead manganese and molybdenum to produce fire or explosion.

6. All hydrazine vapors have a wide flammability range and low spark-ignition flash point temperatures. Hydrazine spills involving dust, rags, cotton, or other porous material with a large surface area may spontaneously ignite from the heat of evaporation.

7. Hydrazine-family fires produce little or no smoke or recognizable visual signatures. MMH, UDMH and A-50 contain some fraction of water, and may produce a flame with a slight yellow-orange colored tinge. Hydrazine fires involving vegetation or other combustibles may produce secondary visible smoke and color signatures. The combustion products of hydrazine fires are also extremely toxic.

C. CHEMICAL AND PHYSICAL PROPERTIES OF NITROGEN TETROXIDE (HYPERGOLIC OXIDIZER)

1. Nitrogen tetroxide is a thick, reddish-brown liquid that is 45% heavier than water. Vapors also are reddish-brown in color, and become recognizable at about 50 ppm. This chemical is extremely toxic, and presents a serious health risk through skin and eye contact, and inhalation routes. It is particularly treacherous, since it has a pungent odor, but produces no strong, immediate irritation. It reacts with skin moisture and with water in the lungs to produce nitric and nitrous acids that destroy contacted tissues. Severe symptoms begin hours after exposure.

2. Personnel in the vicinity of oxidizer transfer or handling operations where liquid or vapor release may occur are required by base regulation to wear the NASA-developed Self-Contained Atmospheric Protective Ensemble (SCAPE). This is a fully-encapsulated outer garment with a tethered or self-contained breathing air supply.

3. Nitrogen tetroxide boils at 70 °F, and its vapors are about three times heavier than air. It evaporates five times faster than water and hydrazine at about 0.1 pounds per minute per square foot. Thus, a 0.1 inch thick spill surface will evaporate in about 5.2 minutes. Reddish-brown oxidizer vapors are easily recognizable by personnel in the incident area and by responding fire fighters.

4. Nitrogen tetroxide and its vapors explode on contact with hydrazine fuels, amines and furfuryl alcohol. Additionally, it can cause ignition on contact with wood, paper and hydrocarbon fuels. Mixtures of N_2O_4 with partially halogenated solvents (carbon tetrachloride, TCE, perchloroethylene, etc.) can be initiated by heat and shock to produce a violent explosion.

5. N_2O_4 is not flammable. However, when added to a fire, it enriches the fire intensity of combustion and burning rate by providing an additional oxygen source. Oxidizer-enriched fires will produce more heat and be more difficult to extinguish. Oxidizer-enriched fires will produce the color and smoke signatures normally associated with NFPA Class A and B fires (fires involving wood, paper and hydrocarbon fuels).

D. HUMAN EXPOSURES TO HYPERGOLIC PROPELLANTS

1. Hydrazine and Nitrogen Tetroxide vapors are extremely toxic. The American Conference of Governmental Industrial Hygienists (ACGIH) annually publishes a booklet entitled *Threshold Limit Values For Chemical Substances and Physical Agents and Biological Exposure Indices*. Threshold Limit Values (TLVs) are the maximum time-weighted average (TWA) concentrations permitted for normal, 8-hour per day, 40- hour per week worker exposure without protective equipment. Hypergolic propellant TWA-TLVs are:

Table III-1. Threshold Limit Values (TLVs) For Hypergolic Propellants

Chemical	Current Level	Proposed Level
Hydrazine	0.1 ppm	.01 ppm (10.0 ppb)
MMH	0.2 ppm (Ceiling)	.01 ppm (10.0 ppb)
UDMH	0.5 ppm	.01 ppm (10.0 ppb)
A-50	None, but UDMH is the most volatile component.	
N_2O_4	3.0 ppm*	n/a

* - TLV for NO_2, since $N_2O_4 \Rightarrow 2(NO_2)$ in the atmosphere.

2. The proposed levels are contained in the ACGIH booklet's "Notice of Intended Changes" section. They will be considered for adoption during 1995. All ACGIH TWA-TLVs automatically become Air Force Occupational Safety (AFOSH) standards, according to AFOSH Standard 48-8, *Controlling Exposures To Hazardous Materials.*

E. FIRE AND VAPOR SUPPRESSION OF HYPERGOLIC PROPELLANTS

1. Fire Suppression Using Commercially-Available Agents

a. There are very sparse data on fire extinguishing agents and fire suppression techniques for hydrazine-family fires. This is because of the toxic and explosive threats of handling the materials, and the environmental restrictions governing their release to air, water and/or ground. Most references date back to the 1960's and were prepared to support the early Titan ICBM program. The following paragraphs summarize relevant information for study and application by CCAS and VAFB fire department personnel.

b. Hydrazine Water Extinguishment

(1) Water and water sprays cool hydrazine fires and dilute the fuel to a level that will not support combustion. A dilution rate of 10 parts water to 1 part hydrazine is a generally accepted rule of thumb for extinguishing an established fire. Additionally, hot metal surface re-ignition should be expected, since hydrazines have auto-ignition temperatures in the 382 - 482 °F range.

(2) Water application by crash vehicle turret or hand-held hose may disperse the hydrazine and "blow" it outside its original boundaries to produce a larger fire surface area. Spills on outside pavement and soil surfaces will flow with the prevailing terrain and become discontinuous from depressions, curbs, drainage sumps or other surface irregularities.

(3) The application of water to produce a uniform 10:1 dilution for the entire spill surface may be difficult to achieve. In their 1960 - 1961 Code, the National Fire Protection Association (NFPA) recommended application rates from 0.20 to 0.75 gallons per minute per square foot (gpm/sf).

(4) More recent live fire extinguishment data indicate that rates at the higher end of this range will be required for effective extinguishment, particularly if hot metal re-ignition can occur:

- A CCAS Fire Department P-19 attempted to extinguish a 64 square foot hydrazine pool fire in March 1994 at the Kennedy Space Center hypergolic propellant training pit.
- Approximately 600 gallons were used before the fire was extinguished.
- Video of the training exercise are inconclusive as to whether the fire was actually extinguished, whether the fuel source simply was expended, or whether the fuel was expelled from the fire pit by the force of the P-19 roof turret stream.
- It is feasible that all three factors contributed to extinguishment.

c. Hydrazine Dry Chemical Agent Extinguishment

(1) Sodium bicarbonate dry powder agents are reported to be effective against hydrazine fires. However, a CCAS Fire Department P-20 crew attempted to extinguish a 64 square foot pool fire in March 1994 at the Kennedy Space Center hypergolic propellant training pit.

(2) A full 500-pound tank application of Purple K agent (Potassium Bicarbonate) appeared to have no effect on the fire. The presence of a hot steel rim surrounding the fire pit fuel mixing sump may have affected extinguishment performance by providing a source of continuous re-ignition.

(3) NFPA-recommended application rates (1960 - 1961 Code) are from 0.065 to 0.1 pounds per square foot.

d. Hydrazine Foam Extinguishment and Vapor Suppression (AFFF, AFFF-P, Alcohol & Protein Foams)

(1) Limited tests of six percent AFFF were conducted by the Air Force Fire Protection Laboratory on 50 square foot MMH fires. The application rate was 0.12 GPM per square foot, and extinguishment times were 75 and 171 seconds for the two tests conducted. AFFF was reported to break down following extinguishment, and burn-back resistance was not published.

(2) Although limited in scope, these results indicate that the 3 percent AFFF currently carried on P-4 and P-19 crash vehicles at CCAS and VAFB should be the first-choice agent for extinguishing hydrazine fires.

- The water in the AFFF stream can dilute the ponded hydrazine spill, cool the fire surface and seal the hydrazine from its atmospheric oxygen source.
- The AFFF surfactant also will seal off hydrazine vapors and prevent reignition from nearby hot metal or flame sources, as long as the film surface remains intact.
- AFFF also should provide some measure of short-term vapor suppression for non-ignited spills.

(3) Alcohol, protein and combination foams (AFFF-P) produce a more durable foam structure and are reported to be acceptable extinguishing agents. They also should provide longer-term vapor suppression action, because of their increased stability. NFPA-recommended application rates (1960 - 1961 Code) for alcohol foam are from 0.1 to 0.27 gpm/sf.

e. Extinguishment of Oxidizer-Enriched Hydrocarbon Fuel Fires

(1) Air Force Fire Protection Laboratory tests of 30 gallons of nitrogen tetroxide mixed with 30 gallons of diesel fuel produced a high-intensity fire with white, rather than the normal yellow-orange flames. The extinguishment mechanism reported was the application of water in a 10:1 ratio to dilute the nitrogen tetroxide to the extent it no longer supported the combusting diesel fuel. The remaining air-supported diesel fuel fire was then extinguished with AFFF.

(2) However, 75 percent of the diesel fuel had burned before final extinguishment was attained. This indicates an extremely inefficient extinguishment mechanism, even though the addition of water was easily applied into a fixed metal burn pan test apparatus. Such ease of application and mixing will not be attainable under most anticipated oxidizer spill conditions.

2. Fire Extinguishment Using Air Force Fire Protection Laboratory-Tested Acrylic-Modified Foams

Extensive vapor suppression and fire extinguishment tests of hydrazines and N_2O_4 were conducted by the Air Force Fire Protection Research Laboratory in the 1985 - 1986 time frame at the Nevada Test Site.

a. The most effective foam formulation for hydrazine fires consisted of a volumetric proportioning of 10 percent Rohm and Haas Polycrylic ASE-95 Fuel Foam , 10 percent Mine Safety Appliance Research (MSAR) Corporation surfactant, and 80 percent water. Best results were obtained when the foam was applied in a 5 to 10:1 low expansion mode.

b. The most effective foam formulation for N_2O_4-enriched fires consisted of a volumetric proportioning of 10 percent Rohm and Haas Polycrylic ASE-60 Oxidizer Foam, 10 percent Mine Safety Appliance Research (MSAR) Corporation surfactant containing a small amount of pectin, and 80 percent water. Best results were obtained when the foam was applied in a 150 to 300:1 high expansion mode.

c. A non-fire department inventory portable foam-dispensing system is required to apply an acrylic foam agent. The apparatus requires two pre-mix tanks, one for the gelling agent foam and water; and, one for the surfactant and water. Each pre-mix tank flows product to a single proportioning valve from separate lines. The blend is dispensed from a foam-producing nozzle. A high pressure nitrogen injection system is used to propel the foam the maximum throw distance.

d. Since the foam formulations are different for fuel and oxidizer applications, separate foam carts will be required, depending on the propellant threat commodity.

e. A Preliminary Foam Suppression System Concept Of Operations:

- Fixed and/or mobile units would be stationed at each CCAS and VAFB fuel and oxidizer bulk storage area.
- Fixed and/or mobile units would be pre-positioned inside each Titan launch complex: one at the Fuel Handling Area (FHA), and one at the Oxidizer Handling Area (OHA).
- Several mobile units would be available for both oxidizer and A-50 fire and vapor suppression during Delta Stage II and Titan Stage I, II and TVC loading.
- Additional mobile units would be required at each fire station and substation to cover emergency response to spills and fires.
- All fixed and mobile units would be charged and ready for operation by designated and trained propellant transfer first responders and/or fire fighters.

SECTION V

KNOWLEDGE BASE OF HYPERGOLIC PROPELLANT-UNIQUE FIRE DEPARTMENT OPERATIONAL REQUIREMENTS

A. FIRE DEPARTMENT MISSION AREAS

1. The CCAS and VAFB fire departments are organized and manned for two primary missions: prevention and operations. Mission area interfaces with space launch-unique facilities and systems are identified.

2. Prevention includes establishing standards and ensuring compliance with Air Force, DoD, National Fire Protection Association (NFPA), and Occupational Safety and Health Administration (OSHA) standards for life safety and facility fire detection and suppression systems. This mission primarily interfaces with the facilities and installed systems that support or protect launch vehicles and payloads, personnel and equipment during hypergolic propellant hazardous operations.

3. Prevention examples include the specification of fire detection and suppression systems, and the design of facility areas to ensure adequate means of emergency egress. The latter is extremely important for the high-rise launch towers and elevated clean room facilities found on CCAS and VAFB. Emergency egress encompasses escape pathways, escape route lengths, exterior exit location and size, and protected stairwells to enable both the horizontal and vertical safety of occupants during a fire or toxic chemical release incident.

4. Operations involve the execution of fire suppression and rescue tasks and training. This mission area interfaces with hypergolic propellants in the arena of emergency response following an accidental release. A propellant release emergency involving a large quantity of either fuel or oxidizer (100 - 400 gallons) can require a significant expenditure of fire department resources. Response operations would be conducted in a toxic vapor environment, and would include:

- Suppression and extinguishment of: non-pressurized fires involving hydrazine, oxidizer-enriched fires, and/or collateral brush/debris fires caused by propellant fires or other ignition sources.
- Suppression and extinguishment of pressurized hydrazine fires to enable leak isolation and/or fuel cut-off.

- Suppression and extinguishment of hydrazine pool fires, oxidizer-enriched fires, pressurized hydrazine fires, or collateral brush or debris fires to enable the rescue of trapped or injured personnel.
- Rescue of personnel from toxic propellant atmospheres and/or damaged facilities.

B. DATA GATHERING APPROACH

1. CCAS and VAFB fire departments and other launch support organizations were visited to determine generalized fire protection operations that are unique to the AFSPC mission. Base visits consisted of tours of launch complexes, propellant storage areas, and payload processing facilities. Technical and operational details on propellant transfer hardware and equipment were obtained. Fire department policies and procedures in support of hazardous propellant transfer operations, as well as generalized emergency response actions, were defined.

2. Primary facilities and/or organizations visited included:

- Fire Department - Fire Chief and senior staff.
- Safety Offices responsible for range and system safety.
- Propellant storage, handling and distribution organizations and facilities.
- Propellant transportation and transfer ground support equipment (GSE) maintenance facilities and equipment.
- Launch complex propellant holding and transfer facilities.
- Launch complex Mobile Service Tower (MST) elevated clean rooms and payload fueling equipment.
- Ground level clean rooms and payload fueling equipment.
- NASA Kennedy Space Center Fire and Rescue Office.
- NASA Kennedy Space Center laboratories involved in hypergolic propellant vapor and flame detection technologies.

3. At each launch support, propellant storage area and payload processing facility, the analysis team requested facility infrastructure and organizational information relating to hypergolic propellant hazardous operations and fire department prevention measures or emergency response. Data were segregated according to four fundamental operational mission perspectives:

- The responding fire department as a unit, or team;
- The individual fire fighter engaged in a hypergolic chemical fire and/or vapor release emergency response;
- An installed facility fire protection system, and;
- The fire protection and emergency response parameters associated with the configurations of the unique high-rise facilities that are required to support launch and payload processing operations.

C. OPERATIONAL INTERFACES

1. Each of the four mission perspectives cited above involves some measure of fire department, fire fighter and/or fire protection system emergency response to the accidental release of hypergolic propellants. Therefore, the analysis team was able to identify the truly unique fire department-hypergolic propellant interfaces that are generated by space launch support. All other data and operational parameters regarding the CCAS and VAFB fire departments were of secondary importance in the analysis.

2. Review of the CCAS and VAFB fire department interfaces with accidental hypergolic propellant releases yielded a significant understanding of the facilities, operations and organizations involved in processing and launching space systems, as well as with the primary elements of fire department emergency response. The major hypergolic propellant accident - fire department mission interfaces requiring detailed analysis were determined to be:

- Fire Department Unit/Team Interfaces

    - Fuel storage area propellant transfer operations and container maintenance and repair.
    - Delta & Titan Launch Vehicle fuel-defuel operations.
    - Titan Fuel & Oxidizer Ready Storage Vessel (RSV) Propellant Transfer/Fill Operations
    - Payload and Centaur reaction control system (RCS) fuel-defuel operations.
    - Propellant container transport vehicle convoy.
    - Fueled payload vehicle convoy.
    - Propellant QA sample containers at storage sites, payload processing facilities, testing laboratory and transport vehicles.

- Individual Fire Fighter Interfaces

  - Fuel storage area propellant transfer operations and container maintenance and repair.
  - Delta & Titan Launch Vehicle fuel-defuel operations.
  - Titan Fuel & Oxidizer Ready Storage Vessel (RSV) Propellant Transfer/Fill Operations
  - Payload and Centaur reaction control system (RCS) fuel-defuel operations.
  - Propellant container transport vehicle convoy.
  - Fueled payload vehicle convoy.
  - Propellant QA sample containers at storage sites, payload processing facilities, testing laboratory and transport vehicles.

- Installed Facility Fire Protection System Interfaces

  - Protection/alarm of personnel involved in hypergolic propellant tasks/operations.
  - Protection of mission-critical payloads and launch systems.
  - Prevention of launch system catastrophic loss.

- High-Rise Space Launch Tower-Unique Interfaces

  - Identification & specification of life safety standards for elevated clean rooms and other work areas.
  - Planning/training of integrated fire department -occupant emergency response to accidental releases of propellants.
  - Delta & Titan Launch Vehicle fuel-defuel operations.
  - Payload and Centaur reaction control system (RCS) fuel-defuel operations.
  - Prevention of launch system catastrophic loss.

D. CCAS/VAFB HYPERGOLIC-PROPELLANT-UNIQUE FIRE DEPARTMENT OPERATIONAL REQUIREMENTS

1. Figure V-1 summarizes the primary hypergolic propellant emergency response interfaces in each of the four fire department mission perspective data categories. Each mission interface area is cross-referenced to five fundamental operational capabilities that are required for the safe and effective response of the CCAS and VAFB fire departments and fire fighters to hypergolic propellant release accidents. These five capabilities also are cross-referenced to facility detection system and high-rise facility configuration requirements that are relevant to launch pad occupant and systems safety.

CCAS/VAFB FIRE PROTECTION REQUIREMENTS CROSS-REFERENCE	*CCAS/VAFB-UNIQUE FIRE DEPARTMENT OPERATIONAL REQUIREMENTS*				
CCAS/VAFB FIRE DEPARTMENT HYPERGOLIC PROPELLANT MISSION INTERFACES	DETECT/SEE HYPER FIRES	SUPPRESS HYPERGOL FIRES	PROTECT FF-HYPER VAPORS, FLAME & HEAT	DETECT HYPER INCIPIENT LEAKS	PROVIDE MST LAUNCH TOWER LIFE SAFETY & EMERGENCY RESPONSE
FIRE DEPARTMENT UNIT/TEAM INTERFACES					
FUEL STORAGE AREA PROPELLANT TRANSFER & MAINTENANCE OPERATIONS	●	●	●	●	
DELTA & TITAN LAUNCH VEHICLE FUEL/DEFUEL OPERATIONS	●	●	●	●	●
TITAN RSV PROPELLANT TRANSFER OPERATIONS (FUEL & OXIDIZER)	●	●	●	●	
PAYLOAD & CENTAUR RCS CLEAN ROOM FUEL/DEFUEL OPERATIONS	●	●	●	●	●
VEHICLE CONVOY W/PROPELLANT CONTAINERS	●	●	●		
VEHICLE CONVOY W/FUELED PAYLOAD	●	●	●		
PROPELLANT SAMPLE CONTAINERS: STORAGE SITES, TRANSPORT VEHICLES & QA LABORATORY	●	●	●		
INDIVIDUAL FIRE FIGHTER INTERFACES					
FUEL STORAGE AREA PROPELLANT TRANSFER & MAINTENANCE OPERATIONS	●	●	●	●	
DELTA & TITAN LAUNCH VEHICLE FUEL/DEFUEL OPERATIONS	●	●	●	●	●
TITAN RSV PROPELLANT TRANSFER OPERATIONS (FUEL & OXIDIZER)	●	●	●	●	
PAYLOAD & CENTAUR RCS CLEAN ROOM FUEL/DEFUEL OPERATIONS	●	●	●	●	●
VEHICLE CONVOY W/PROPELLANT CONTAINERS	●	●	●		
VEHICLE CONVOY W/FUELED PAYLOAD	●	●	●		
PROPELLANT SAMPLE CONTAINERS: STORAGE SITES, TRANSPORT VEHICLES & QA LABORATORY	●	●	●		
FACILITY FIRE PROT. SYSTEM INTERFACES					
ALARM PERSONNEL OF HAZOPS EMERGENCIES	●			●	
PROTECT PAYLOADS & LAUNCH SYSTEMS	●	●		●	
PREVENT CATASTROPHIC LOSS	●	●		●	●
HIGH-RISE LAUNCH TOWER INTERFACES					
ID ELEVATED FACILITY LIFE SAFETY STANDARDS					●
PLAN/TRAIN FF-OCCUPANT HAZMAT INTEGRATED EMERGENCY RESPONSE			●		●
DELTA & TITAN LAUNCH VEHICLE FUEL/DEFUEL OPERATIONS					●
PAYLOAD & CENTAUR RCS CLEAN ROOM FUEL/DEFUEL OPERATIONS					●
PREVENT CATASTROPHIC LOSS					●

Figure V-1. CCAS and VAFB Fire Department Operational Requirements-Hypergolic Propellants Cross-Reference Matrix.

2. The CCAS/VAFB-unique, fire department operational mission requirements that are generated by the use of hypergolic propellants to fuel space launch vehicles and payload systems are described, as follows:

a. The Capability To Detect Or See Hydrazine Fuel Flames

(1) Fires fueled by Anhydrous Hydrazine, AH (N_2H_4), and its derivatives, Monomeythlhydrazine, MMH (CH_6N_2), Unsymmetrical Dimethylhdrazine UDMH ($C_2H_8N_2$) and Aerozine 50 (A-50), a 50:50 percent mixture of AH and UDMH, produce little or no visible flame and smoke.

(2) Personnel in the vicinity of such fires may be unaware that a fire has occurred until very dangerous secondary effects are recognized, such as an extreme temperature rise, the combustion of nearby materials and/or the melting of the individual's protective ensemble components. Similarly, responding fire fighters will have extreme difficulties in identifying the location and size of a hydrazine fire, its rate of growth and direction of spread. These visual signatures are essential for effective fire suppression and rescue operations.

b. The Capability to Suppress and Extinguish Hypergolic Fuel and Oxidizer-Enriched Fires

Effective agents to extinguish hypergol fires are essential to enable fire fighters to minimize exposures from toxic combustion by-products and the loss of life and property. Vapors from the hydrazine fuels present an extremely dangerous explosion and fire potential, since lower flammability limits range from 2.0% to 4.7% concentration in air for hydrazine derivatives. Similarly, the upper flammability limit for these fuel ranges from 95% to 100% in air. Vapors may spontaneously ignite on contact with dust, an oxide source, such as iron or copper rust/corrosion, or a moderately hot surface (100 ^{o}F).

c. The Capability To Protect Fire Fighters From Hypergolic Vapors And Flames During Fire Suppression And Rescue Operations

(1) Hydrazine and nitrogen tetroxide vapors are extremely toxic. As defined in Section III, the time-weighted average threshold limit values (TWA-TLVs) for all hydrazine-based fuels are less than 1 ppm, and may be lowered to 10 ppb in the near future. Because of these extremely low permissible exposure levels, all CCAS and VAFB fire suppression and rescue operations in the vicinity of hypergolic propellant vapors must be conducted by personnel wearing self-contained breathing apparatus (SCBA) underneath a fully-encapsulated protective ensemble.

(2) CCAS and VAFB fire fighters also must respond to and suppress hydrazine and/or nitrogen tetroxide-enriched fires, should they occur. Hypergolic propellant fire threats may approach 3,000 ^{o}F for oxidizer-enriched fires involving hydrocarbon fuel components or combustible metals. Hydrazine fires require heat and flame protection against a minimum of 2,000 ^{o}F. Toxic vapors and combustion products will be in the vicinity of all hypergolic propellant fires.

(3) Currently, all Air Force fire fighters wear "Level A", fully-encapsulated HAZMAT ensembles, as defined by OSHA 29 CFR 1910.120 (q), *Emergency response to hazardous substance releases,* and implemented by NFPA 471, *Responding To Hazardous Materials Incidents*. "Level A" ensembles provide full protection against inhalation and dermal paths of toxic chemical exposure. These ensembles, however, provide no flame or heat protection and will melt on contact with a flame source.

(4) Air Force fire fighters wear heat-resistant protective clothing and SCBA for suppression and rescue operations. Reflectorized outer garments are worn for aircraft crash-rescue. These ensembles do not provide full-body protection against toxic vapor and liquid exposures.

(5) Thus, by Law, CCAS and VAFB fire fighters cannot respond to hypergolic propellant fires unless they wear fully-encapsulated, OSHA "Level A", ensembles. These ensembles are neither flame- nor heat-resistant. Therefore, fire fighter effectiveness is severely limited, and may not be possible at all in and around the vicinity of a propellant fire. This *"Catch-22"* situation constitutes a major operational deficiency and command and control dilemma for the CCAS and VAFB fire chiefs.

d. The Capability To Detect Incipient Hypergolic Propellant Leaks In Clean Rooms

(1) Minute hydrazine or MMH vapor leaks are colorless and, generally, can be considered the precursor to larger releases that may lead to a catastrophic fire or explosion on the launch pad and in clean rooms. Hydrazine-based fuels only need a small quantity of an oxide source for combustion. Additionally, vapors can flash-ignite expelled as a fine spray from a pressurized container or transfer line or when absorbed by dust and debris particles. Vapor-phase explosions can occur at volumetric concentrations of 2.5% (2,500 ppm) with air for MMH and 4.7% (4,700 ppm) for hydrazine.

(2) Small, detectable leaks, generally, are a precursor to a larger release situation. The capability to detect leaks in their incipient stages, in the 1 - 25 ppm concentration range, can significantly decrease the time to alarm personnel of a potential problem and increase the lead time available for personnel and/or installed systems to take corrective action. The objective of early detection is to decrease the alarm time interval and to provide more reaction time to prevent a vapor phase explosion.

e. Life Safety And Emergency Response Standards For Mobile Service Tower (MST) Elevated Clean Rooms

(1) Universal Environmental Shelters (UES) are constructed on the higher levels of launch pad Mobile Service Towers (MST). They encircle the upper stages and payloads to provide protected access for final servicing, checkout, and propellant loading. Clean rooms are provided where access to payloads and/or fuel transfer ports are required. These facilities are located at elevations over 100 feet above ground level.

(2) There are no USAF, DoD, OSHA or other national life safety and fire protection standards that apply explicitly to MST or clean room facilities and the propellant transfer operations that are conducted inside these structures. Over the years, they have been designed and constructed based on the logical interpretation and "best fit" of the standards that were in force at the time.

(3) Because of the unique hazards associated with elevated clean room facilities, the Air Force and its civilian contractor employers must provide special facility configurations, safety systems, procedures, training, and other safeguards during propellant transfer operations. These are required to ensure compliance with current Federal Law regarding fire protection, worker and workplace safety, and the emergency response to accidental chemical releases.

(4) Air Force Space Command policy for launch tower clean rooms is to apply life safety and fire protection standards according to the following priority sequence: "first protect people, then the payload, and, finally, the facility". Specifically, personnel protection is provided by fire/mishap prevention training, egress training, hazardous/toxic material detectors and alarms, emergency air purge systems, protective equipment and hazardous operation procedures reviews. Compliance with the protected egress provisions of NFPA 101, *Life Safety Code*, also is required.

E. OPERATIONAL CAPABILITY UNIQUENESS

It was determined that the space launch facility fire protection and rescue mission area requires five operationally-unique capabilities that are different from a fire department that supports combat aircraft sortie generation facilities. Figure V-1 clearly indicates the importance of these operational capabilities: most are equally required by each of the four fire protection - hypergolic propellant interface areas. These unique operational requirements, such as the capability to detect or see a virtually invisible hydrazine fire, and the requirement to protect fire fighters from the dual-threat, toxic vapor-propellant fire environment, are critical components of the analysis to follow that identifies and justifies CCAS/VAFB fire protection research and development requirements based on operational needs.

SECTION VI

MOBILE PROPELLANT TRAILERS AND PORTABLE CONTAINERS

A. INTRODUCTION

1. The CCAS and VAFB fire departments are responsible for fire suppression and rescue operations during incidents involving the accidental release of hypergolic fuels or oxidizer. Propellant accidents can occur in three fundamental manners:

a. During The Transfer Of The Commodity From One Container To Another

Releases are generally caused by the material failure of a transfer system component or by improper routing of the propellant outside of a closed-loop system. In such cases the capacities of the containers, to include space system on-board fuel or oxidizer tanks, are important to the planning and execution of fire department emergency response operations.

b. As A Result Of Container Damage

Vehicle accidents on or nearby CCAS and VAFB can occur involving the containers and trailers used for hypergolic propellant distribution. Additionally, accidents may occur when drums or containers are moved with a forklift or crane, when lifted from ground level to a truck bed for delivery, or when off-loaded.

c. As a Result Of Sampling Accidents

Portable propellant containers and large, mobile trailers are sampled for product quality at specified intervals. Fuel samples are placed in glass flasks. Oxidizer samples are drawn into stainless steel Hoke bottles. Releases can occur during the draw operation or as a result of a dropped or spilled glass sample flask.

2. Data regarding the physical size, capacities and configurations of hypergolic propellant containers and trailers are crucial to fire department planning and training for emergency response. Container capacities define the maximum fire and vapor release threat. Configurations and the materials and methods of construction determine probable release points and leak isolation, plug or patch methods.

3. The descriptions and capacities of hypergolic propellant containers used at CCAS and VAFB are summarized in Figure VI-1. This information will be of critical importance for fire fighter education and pre-planning, and for the tactics required for safe and effective operations in the event of an actual accident/incident.

CCAS & VAFB CONTAINERS / CAPABILITIES	CAPACITY (GAL)	PROPELLANTS			
		N2H4	MMH	A-50	N2O4
DOT 5-C DRUMS	55	●	●		
KSC DOT/ASME DRAIN CONTAINERS	5 & 30	●	●		●
SA-ALC 2,000 LB CYLINDERS	200	●			●
PROGRAM-SPECIFIC GSE CARTS	50-250	●	●		●
KSC GENERIC PROPELLANT TRANSFER UNIT (GPTU)	500	●	●		●
KSC TANKER-TRAILERS	2,500	●		●	●
RAIL CARS (CCAS ONLY)*	10,000				●
	7,000	●			

* - Not In Use As Of March 1995.

Figure VI-1. Hypergolic Propellant Portable Container Database.

B. PROPELLANT TRANSPORTATION AND DELIVERY

1. Bulk Supply Deliveries to Central Storage

a. VAFB. All products are off-loaded from 2,500-gallon mobile tankers into bulk storage tanks at the Hypergolic Storage Facility (HSF). Delivery of large quantities to launch facilities also is by 2,500-gallon liquid tankers.

b. CCAS. There are no bulk fuel and oxidizer storage facilities in use at this time. Propellants are stored in 2,500-gallon liquid tankers At Fuel Storage Area #1 (FSA #1). 2,500-gallon vendor tankers may be used, or vendor tankers may be off-loaded into NASA KSC-owned 2,500-gallon tankers.

c. From bulk storage, propellants are distributed to all large quantity launch vehicle users via storage facility-controlled 2,500-gallon tankers. On CCAS, this includes deliveries to Shuttle processing facilities.

2. Bulk Supply Deliveries to Titan IV Fuel and Oxidizer Holding Areas

a. The CCAS and VAFB Titan IV launch complexes have separate hypergolic propellant bulk storage areas, the Fuel and Oxidizer Holding Areas (FHA/OHA). In each area, propellants are stored in diked stainless steel Ready Storage Vessels (RSVs).

b. On VAFB, both fuel and oxidizer RSVs are filled from 2,500-gallon liquid tankers brought from the HSF.

c. On CCAS, Aerozine-50 and nitrogen tetroxide are delivered by 2,500-gallon liquid tankers from FSA #1. Both propellants can be delivered to Titan IV facilities by 10,000-gallon rail car. Rail spurs are not used for bulk deliveries at this time.

3. CCAS/VAFB Drum and Cylinder Deliveries

Anhydrous hydrazine (AH), monomethylhydrazine (MMH) and nitrogen tetroxide (N_2H_4) are delivered to CCAS and VAFB in DOT-approved 55-gallon drums. Hydrazine and N_2H_4 also are delivered in vendor-filled 2,000 pound cylinders provided by the USAF San Antonio Air Logistics Center (SA-ALC), Kelly AFB, Texas. Both drums and cylinders are transported onto CCAS and VAFB stacked on flat bed trucks.

4. NASA-Designed Containers

a. Shuttle Transportation System (STS) propellant handling and safety requirements have resulted in the NASA design and construction of containers in 5-, 30- and 500-gallon capacities. These are generally designated as Kennedy Space Center (KSC) containers.

b. KSC containers are superior to 55-gallon drums by virtue of their higher pressure ratings and impact and puncture resistant designs. They also are pre-plumbed for ease and safety in connecting and product transfer and sampling equipment.

c. KSC 5- and 30-gallon containers are usually filled from 55-gallon drums or larger portable containers. At CCAS, KSC 500-gallon containers, designated Generic Propellant Transfer Unit (GPTUs), are filled from 2,500-gallon tankers in the FSA #1 trailer holding areas.

d. KSC containers are used for both CCAS and VAFB deliveries to hypergolic propellant users.

5. Small Container On-Base Deliveries

55-gallon drums, and KSC 5- and 30-gallon containers are, generally, transported by flat bed or pickup truck both on CCAS and VAFB to end-user destinations. On CCAS, the KSC 500-gallon GPTU container is transported on a specially-designed, impact-resistant, trailer for delivery routes from FSA #1 to KSC shuttle and payload processing facilities.

C. MOBILE AND PORTABLE HYPERGOLIC PROPELLANT CONTAINERS

1. Figure VI-2, 55-Gallon Drums (AH & MMH)

These are DOT-5C compliant drums constructed of welded A-304 grade stainless steel. They are pressure-rated at 0-15 psi.

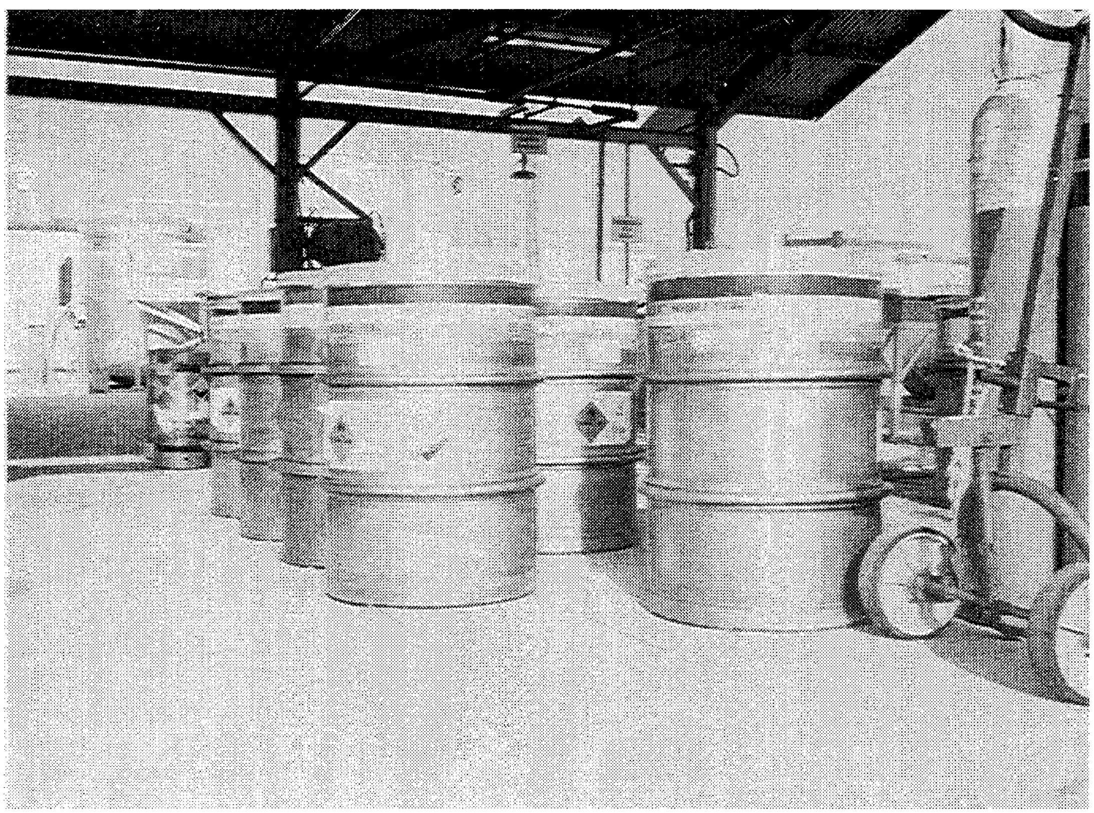


Figure VI-2. 55-Gallon Drum Containers.

2. Figure VI-3, 2,000 - Pound SA-ALC Containers (AH, MMH & N_2O_4)

These hydrazine and oxidizer containers are pressure vessels constructed of mild steel. They are pressurized by an inert nitrogen blanket to 10 psig during transportation and storage. They are DOT-approved for road shipment.

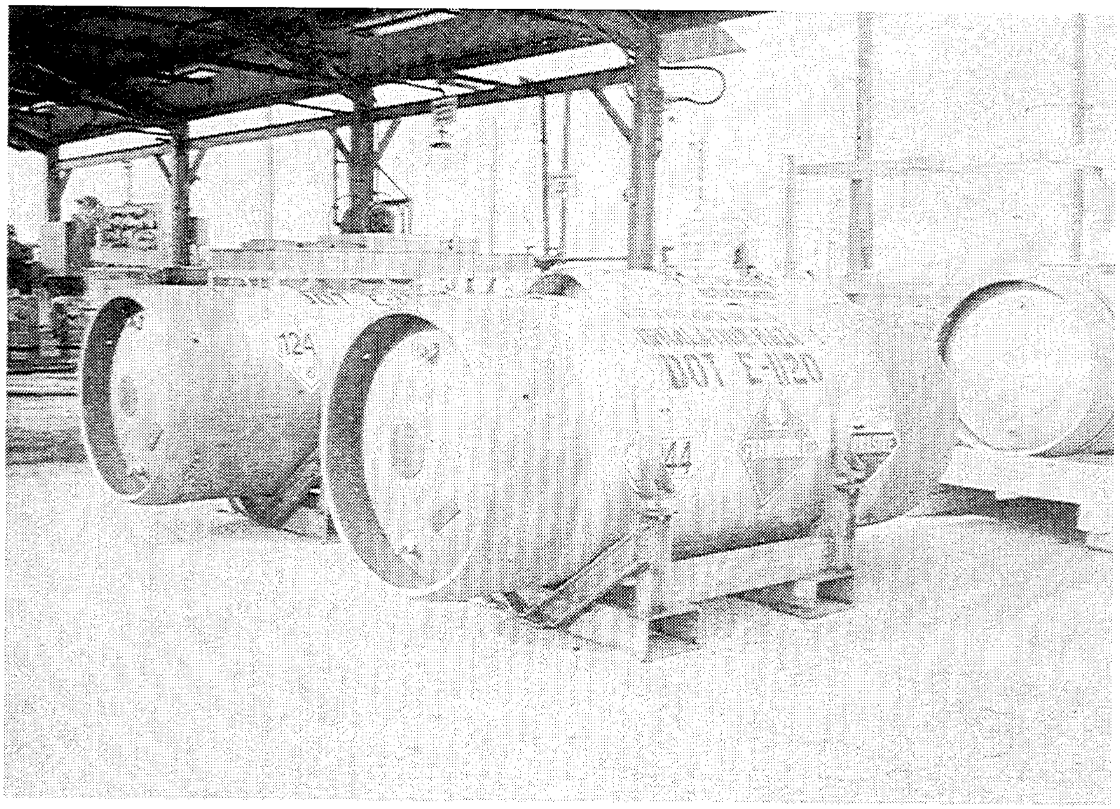


Figure VI-3. 2,000-Pound SA-ALC MMH Containers.

3. Figures VI-4, VI-5 & VI-6, 5- and 30-Gallon KSC Drain Containers (Oxidizer & Fuel)

a. These containers, Figures VI-4 and VI-5, are constructed of A-304L stainless steel. They feature an integral protective skirt at the top of the tank that is raised above the gage and connection plumbing attached to the tank top, Figure VI-6. The skirt prevents damage to the fill and vent components during a drop or transport vehicle accident. Drain holes at the skirt-cylinder interface prevent the build-up of the commodity around plumbing connections.

Figure VI-4. 30-Gallon KSC Drain Containers (AH).

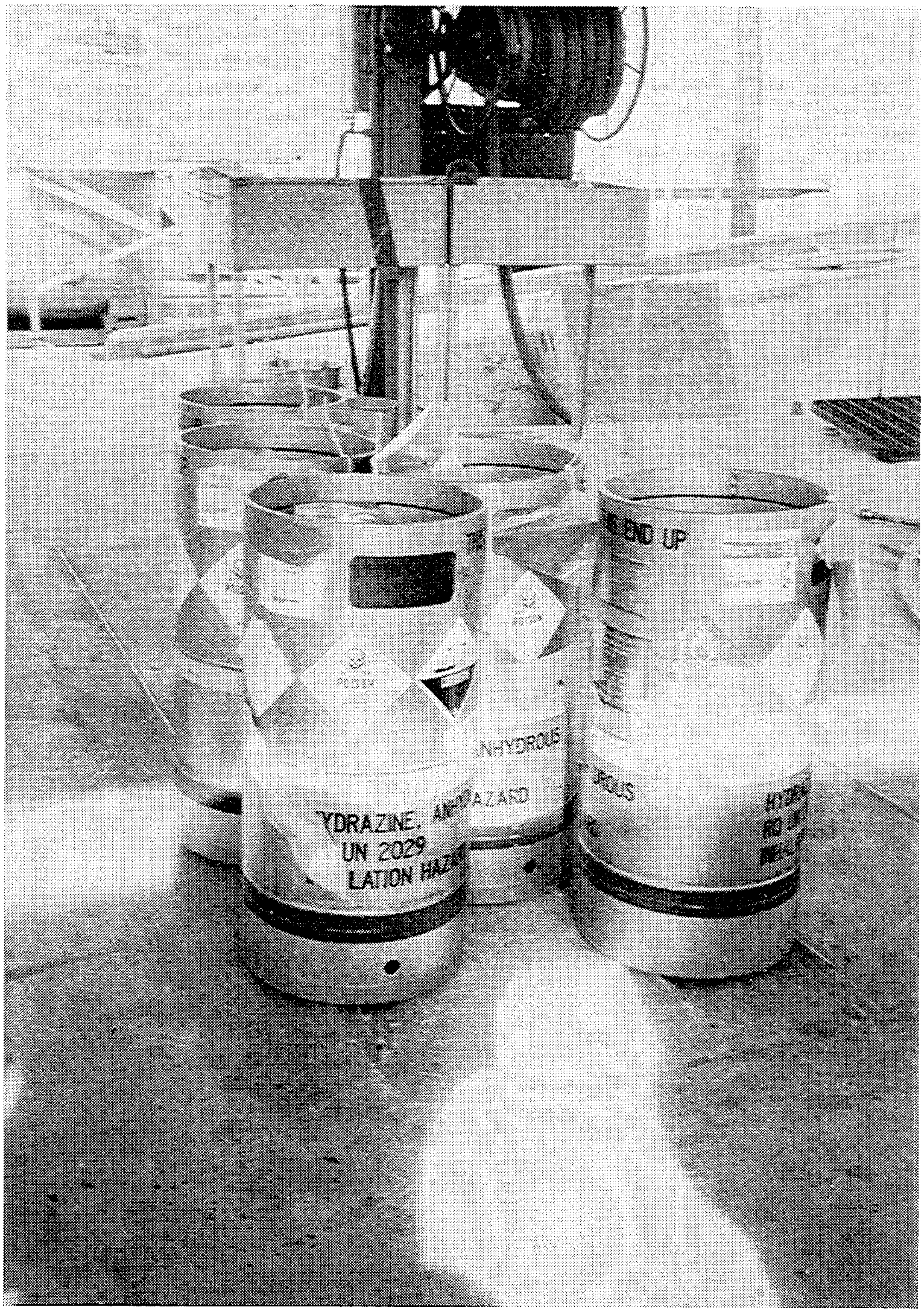


Figure VI-5. 5-Gallon KSC Drain Containers (N_2O_4).

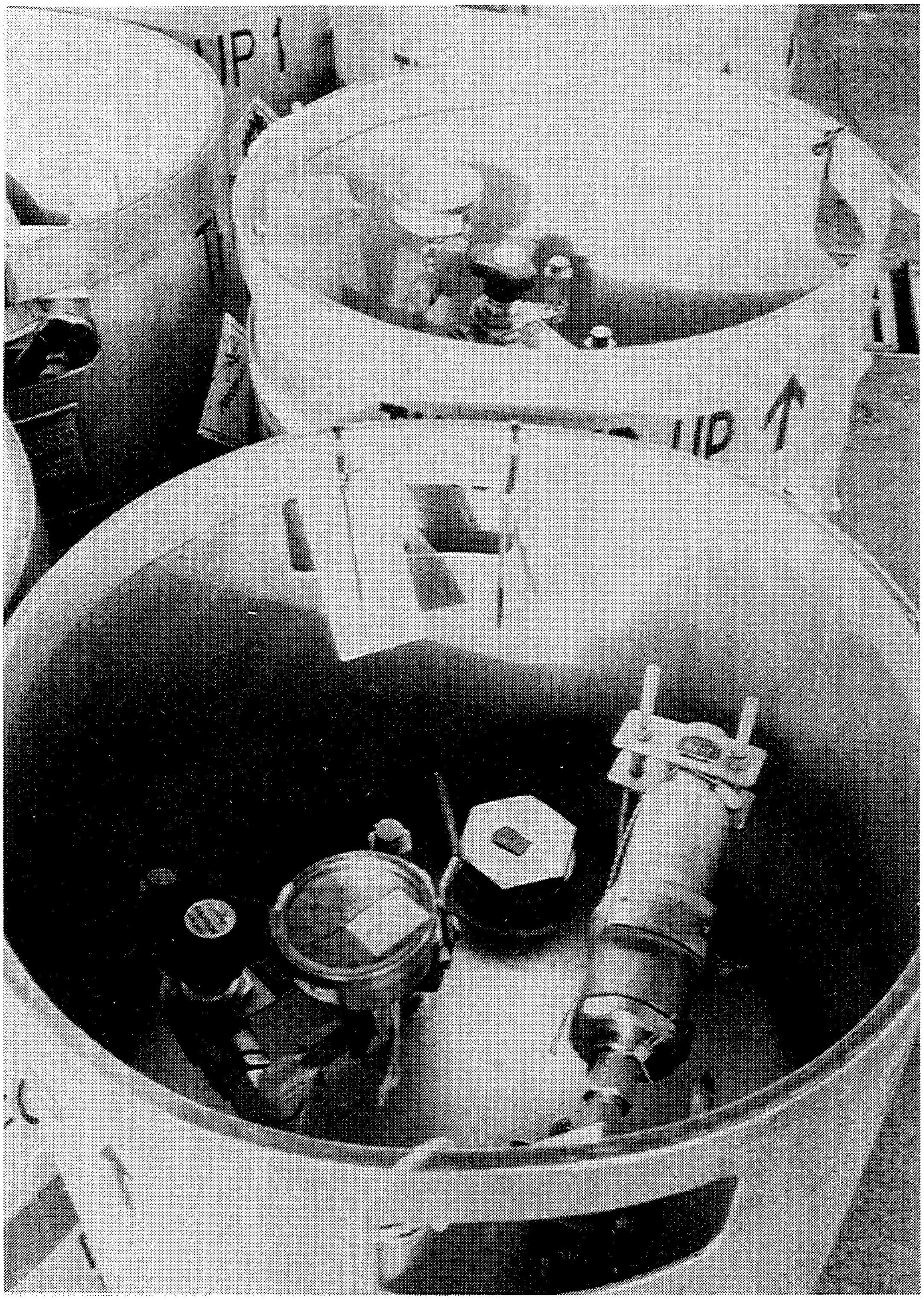


Figure VI-6. KSC Drain Container Raised Protective Skirt.

b. KSC drain containers are pre-plumbed with a pressure relief valve, funnel fill cap, fluid inlet and outlet connection, and a vent/purge connection. The maximum allowable working pressure is 100 psig.

c. KSC drain containers are delivered to NASA KSC, CCAS and VAFB end-users.

4. Figures VI-7, VI-8 And VI-9, KSC 500-Gallon Generic Propellant Transfer Units (GPTUs) For Oxidizer & Fuel

a. GPTUs, Figure VI-7, consist of a 550-gallon, A-304L stainless steel inner ASME lethal service pressure vessel. The payload is 500-gallons, and there is a 50-gallon ullage. An outer stainless steel vessel completely surrounds and encapsulates the inner vessel. The cavity is charged with dry nitrogen to prevent corrosion of the inner vessel.

b. The inner vessel has only one opening, which is a 19 inch diameter manway at the top. Pre-plumbed fill and discharge connection fittings and valves are recessed in the area between the outer and inner vessels, Figure VI-8. The pressure relief valve is set at the maximum allowable working pressure of 300 psig.

c. GPTUs are designed to be lifted by a forklift or crane and transported on single and double unit GPTU stainless steel safety trailers, Figure VI-9.

d. GPTUs are delivered to KSC shuttle and payload processing facilities. The may be delivered to Air Force end-users on CCAS via written agreement with the NASA propellants office.

5. Figures VI-10, VI-11 and VI-12, KSC 2,500-gallon Liquid Tankers (Fuel & Oxidizer)

a. KSC tankers, Figure VI-10, consist of a dual-wheel, tandem axle, frameless chassis assembly on which is mounted a 2,760-gallon liquid storage tank encapsulated in a protective outer steel jacket. The propellant tank has a 2,500-gallon payload and a 260-gallon ullage.

b. The inner vessel is A-304L stainless steel. It has only one opening, which is an 18 inch diameter manway at the top, rear of the tank. Pre-plumbed fill and discharge connection fittings and valves are recessed in the area between the outer and inner vessels, Figure VI-11. The pressure relief valve is set at the maximum allowable working pressure of 300 psig.

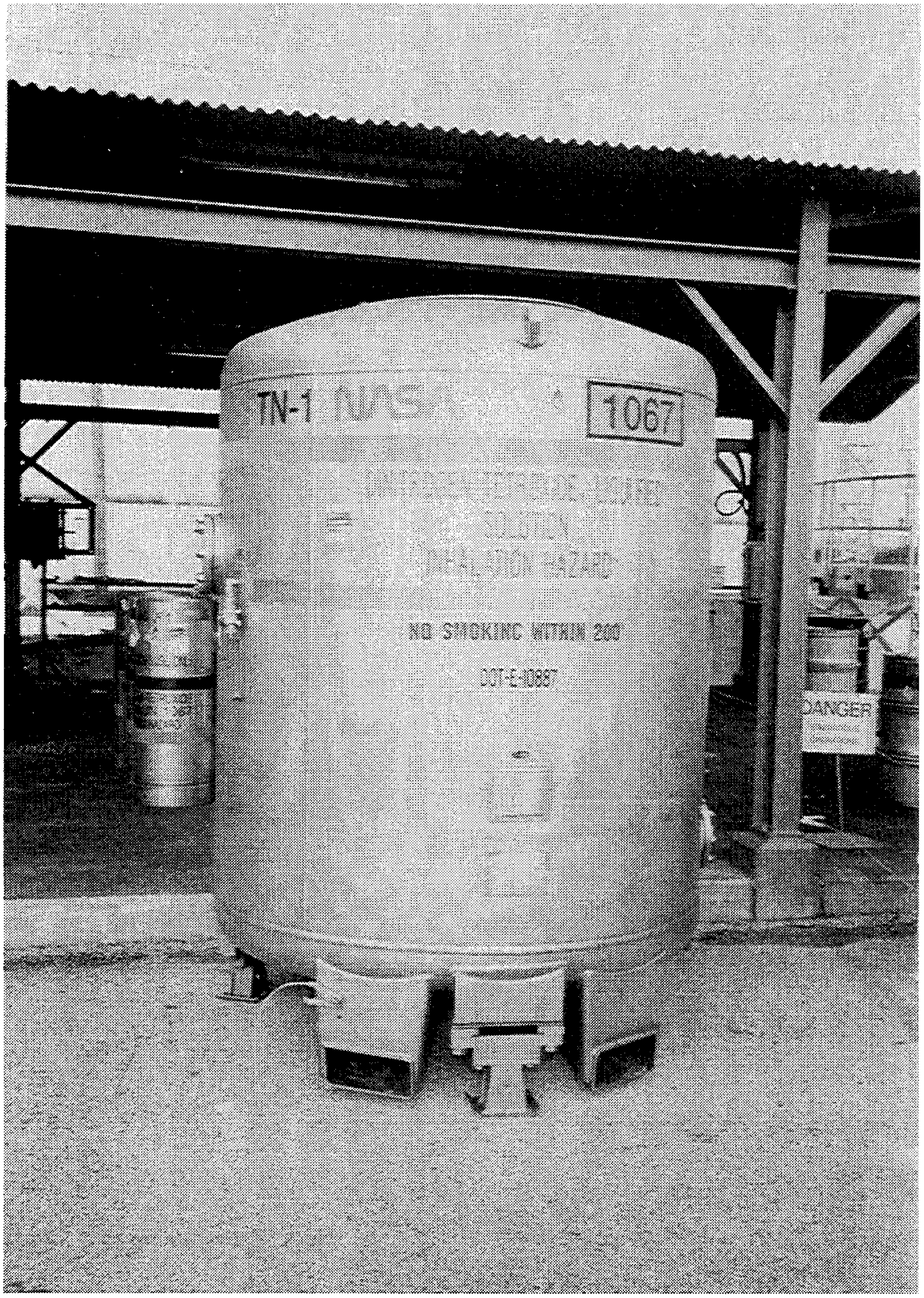


Figure VI-7. KSC 500-Gallon Generic Propellant Transfer Unit.

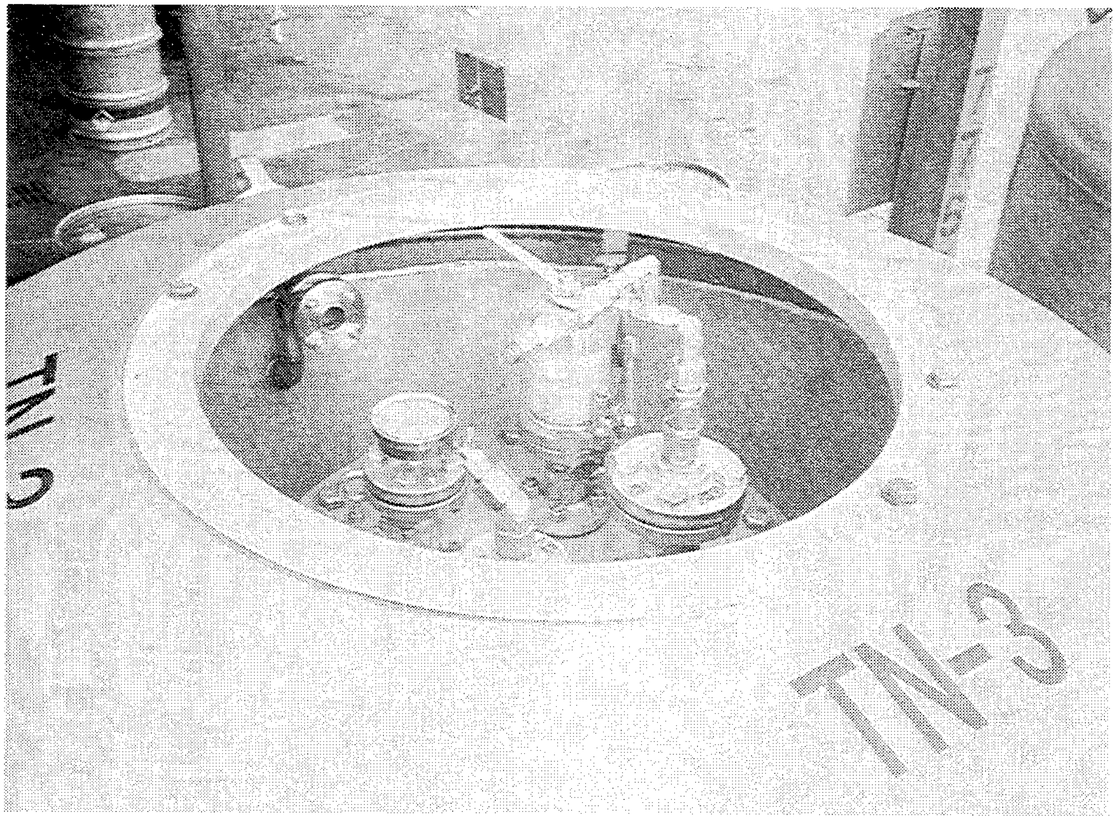


Figure VI-8. KSC 500-Gallon GPTU Fitting Sump.

c. KSC tankers are constructed with an emergency leak containment system and with crash protection features. They are rupture and penetration-resistant to credible vehicle accident scenarios on and off CCAS and VAFB.

d. Propellant transfer units for the loading and off-loading of liquids to containers, bulk storage tanks or on-board launch vehicle fuel and oxidizer tanks are located at the rear of each mobile trailer, Figure VI-12.

6. CCAS Vendor Trailer Deliveries (Fuel and Oxidizer)

For deliveries to CCAS from propellant chemical refineries, vendor-owned 2,500-gallon KSC trailers are used.

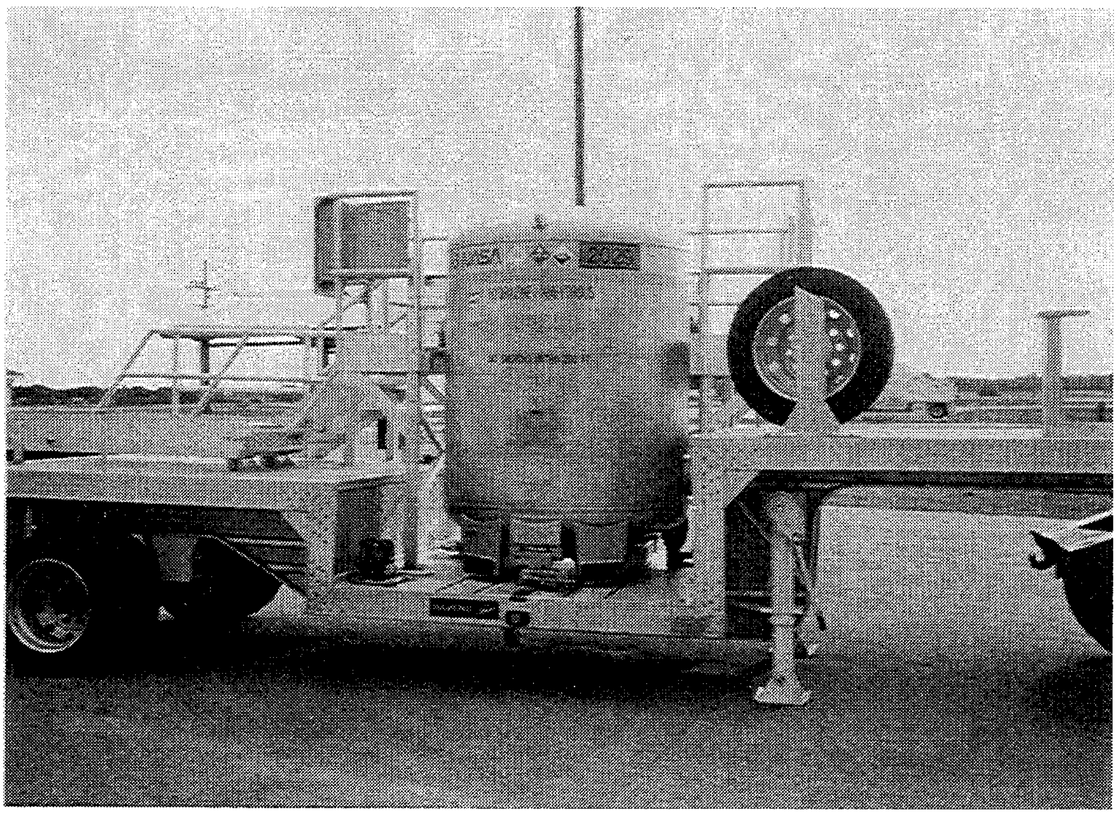


Figure VI-9. KSC 500-Gallon GPTU and Single Unit Trailer.

Figure VI-10. KSC 2,500-Gallon Liquid Tanker.

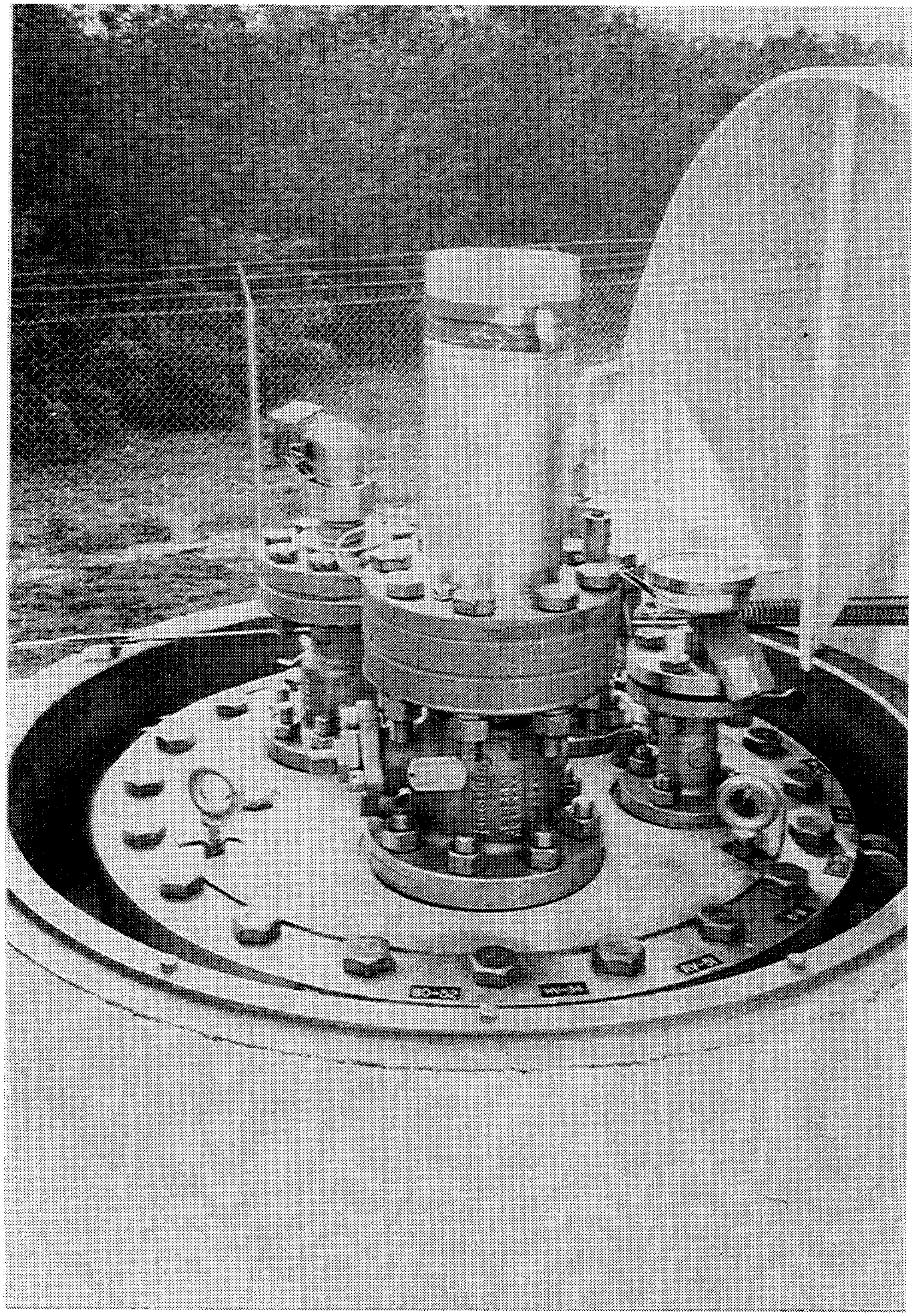


Figure VI-11. KSC 2,500-Gallon Liquid Tanker Fitting Sump.

Figure VI-12. KSC 2,500-Gallon Liquid Tanker Propellant Transfer Unit.

SECTION VII

HYPERGOLIC PROPELLANT FIXED BULK STORAGE FACILITIES

A. INTRODUCTION

1. Propellant bulk storage tanks located on CCAS and VAFB are large reservoirs of highly toxic chemicals. The fuels also are very flammable and explosive. Commodities are moved to and from these tanks through propellant transfer units (PTUs). These are fixed and portable systems that draw or push fluids from one tank or container to another. PTUs are connected to bulk storage tanks by fixed distribution pipe networks. Mobile trailers and rail cars are off-loaded to fixed manifold systems through lengths of flexible stainless steel hose.

2. Fire department units must be trained and equipped to respond to an accidental hypergolic propellant release or fire during transfer operations. Releases can be caused by:

- Material failures, such as fractures, separations, or perforations, in propellant distribution system and/or PTU pipes, valves, gages, or other components.
- Improper seating/sealing of stainless steel hose temporary connections.
- Overfilling tanks into vent system pipe runs.
- Improperly routing hazardous commodities to an open tank or sump.

3. Key data for fire department incident management and control will include the location of the release, the storage tank size, the mechanism of the release, and the rate of product flow from the release point(s).

B. CCAS FUEL STORAGE AREA #1 (FSA #1)

1. A general site plan for FSA #1 is at Figure VII-1. There are no permanent, fixed fuel or oxidizer storage tank facilities at CCAS that are in use at the present time. Bulk supplies of A-50 and oxidizer are stored in vendor and KSC 2,500-gallon tanker-trailers positioned on hardstands at dispersed areas throughout FSA #1. Fuel and oxidizer 500-gallon Generic Propellant Transfer Units (GPTUs) also are used for bulk storage on dispersed hardstands.

2. Small fuel containers, consisting of 55-gallon drums and KSC 30- & 5-gallon drain containers are stored at the hydrazine drum storage area. This consists of an open-walled covered shed facility on a concrete slab. Drums and containers rest on exposed grounding rods to prevent the

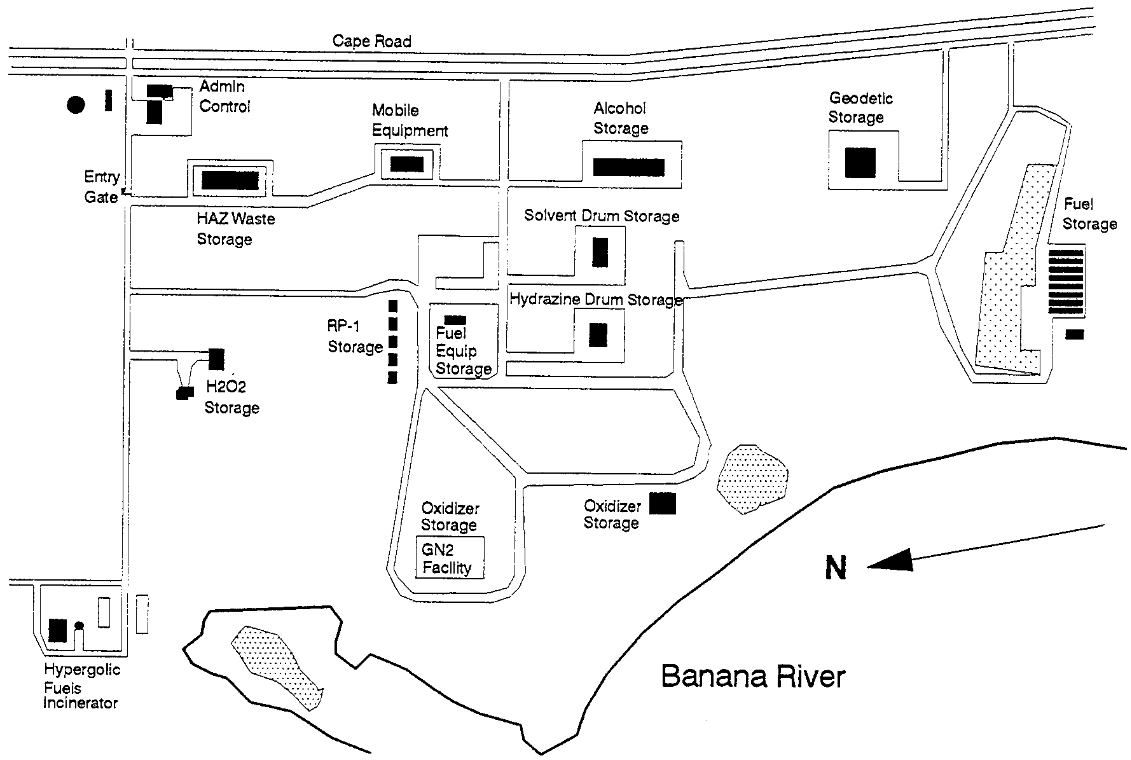


Figure VII-1. CCAS Fuel Storage Area #1 Site Plan.

build-up of wind-generated static electricity. Fire protection is provided by an open head deluge system with heat detectors. Spills and deluge water run off to a center sump, and then to a buried 800 gallon stainless steel tank.

C. VAFB HYPERGOLIC STORAGE FACILITIES (HSF)

1. The HSF fuel facility site plan is at Figure VII-2. Two clusters of three 28,000 gallon stainless steel tanks are mounted in a concrete containment basin. Each tank within a cluster is manifolded to the others, and each cluster is manifolded together. Tank containment overflow is to a 1,000,000 gallon catch basin. Fire suppression and spill dilution are provided by an open head deluge system activated by cross-zoned UV/IR sensors.

2. A fixed-pipe propellant transfer system is used for load and offload operations and inter-tank propellant movements. Trailers are off-loaded by nitrogen overpressure and linked to the load/offload connections by flexible stainless steel hose lengths. The nominal operating pressure is 35 psig, and the peak transfer rate is 100 gpm.

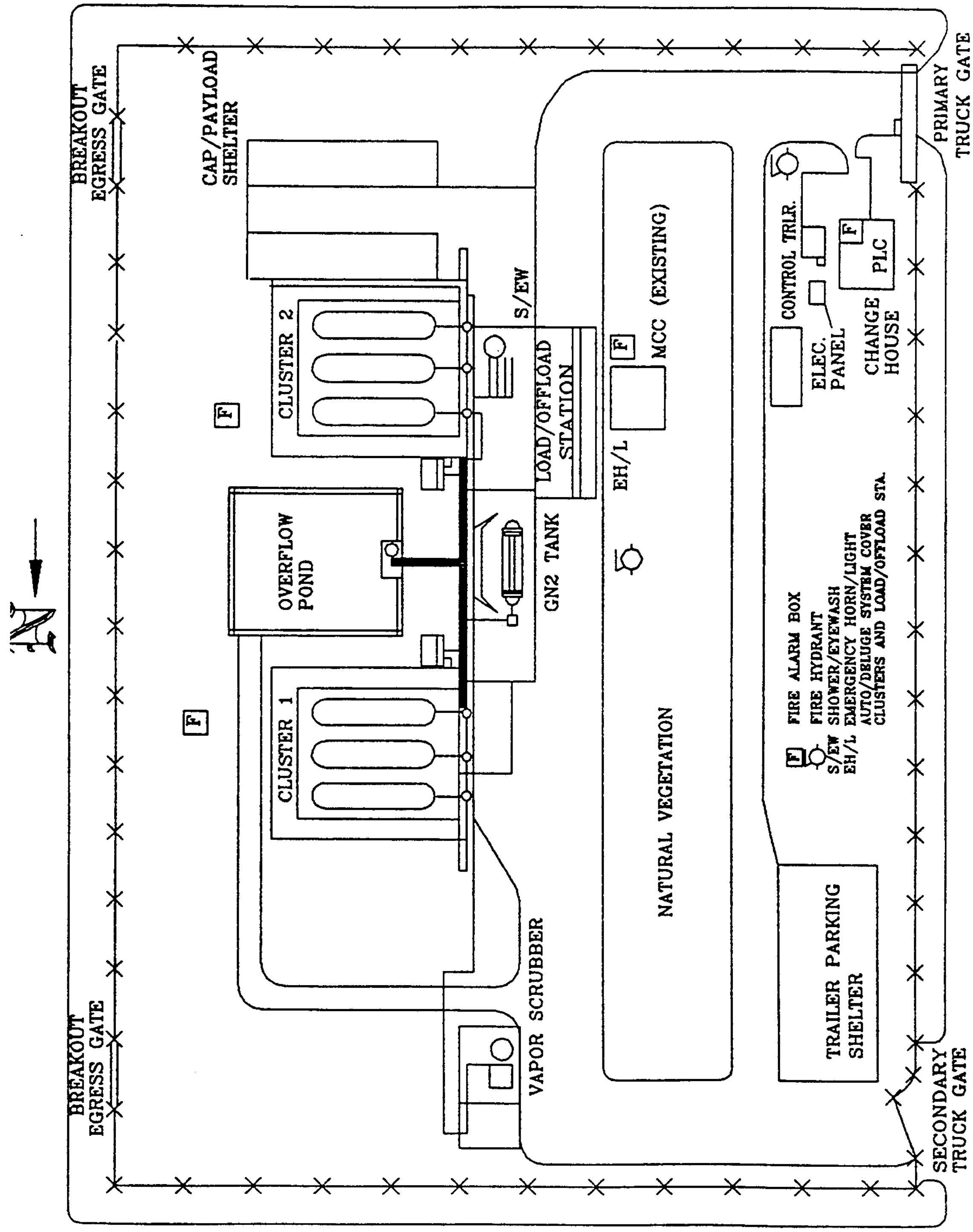


Figure VII-2. VAFB HSF Fuel Facility Site Plan.

3. A covered, open-walled drum storage facility abuts the South cluster of three tanks. It is used to store 55-gallon drums of N_2H_4 and MMH used for payload fueling.

4. The HSF oxidizer facility is identical in plan and capacity to the fuel facility. It is in a dispersed area from the fuel storage site.

D. CCAS TITAN IV FUEL AND OXIDIZER HOLDING AREAS

1. Figure VII-3 shows a generalized schematic of the Fuel Holding Areas (FHA) at Launch Complex 40 and 41. Each FHA contains two 11,000 gallon stainless steel fuel storage tanks designated as Ready Storage Vessels (RSVs), a Propellant Loading Unit (PLU), and an off-load area for three railroad tank cars and one, wheeled tanker trailer.

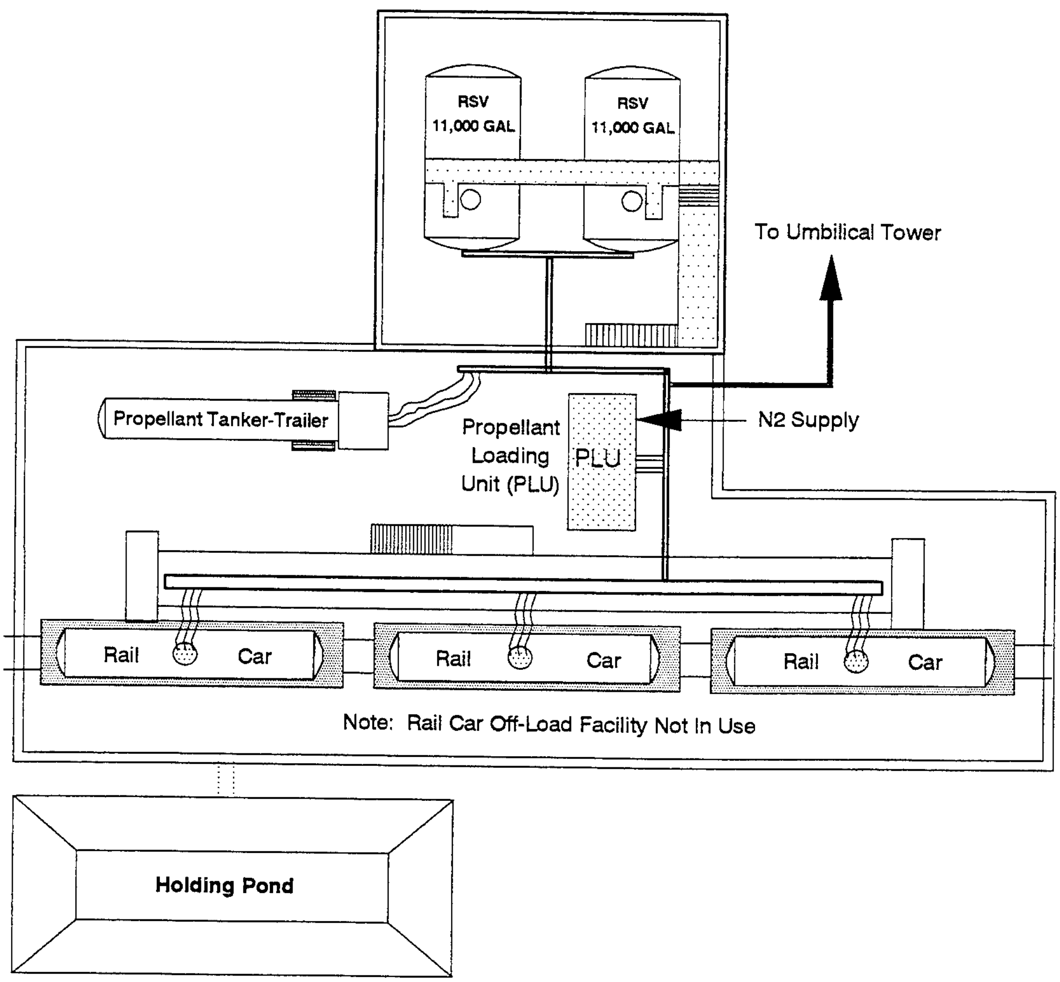


Figure VII-3. CCAS Titan Fuel Holding Area (FHA) Site Plan.

2. The CCAS Titan FHA rail car off-load area is shown at Figure VII-4.

3. RSVs are contained in a concrete catch basin, Figure VII-5. Fuel spilled in the containment, around the PLU, or in off-load areas, flows into grated drains and into a 500-gallon sump. The sump overflows into a 50,000 gallon holding pond.

4. The PLU, Figures VII-6 and VIII-7, is mounted on a concrete pad and contains a centrifugal pump, flow meters, automatic flow control system, nitrogen pressure controller, flow meter verification system, and associated check valves and other piping and distribution components. Nitrogen pressure is used to off-load fuel from rail cars and tankers. The centrifugal pump is used for Titan launch vehicle loading.

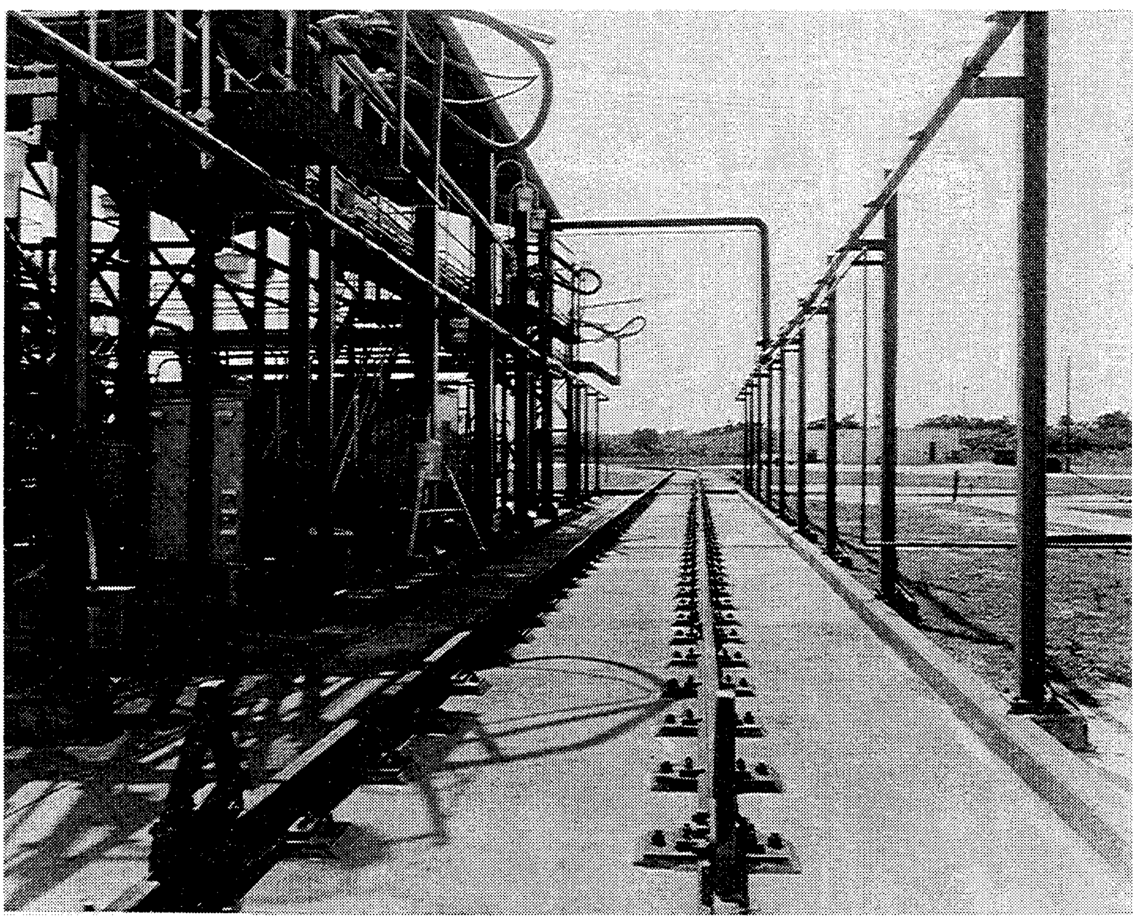


Figure VII-4. CCAS Titan FHA Rail Car Off-Load Terminal.

5. A deluge water system provides fire suppression and spill dilution. It is activated by rate-compensated, fixed temperature heat detectors located above the RSVs and PTU, and along the railroad offload area. Deluge water is supplied from a 1.25 million gallon elevated tank at Pump Station #7, which serves both SLC 40 and 41. The pump station has two pumps to provide a deluge flow rate of 1, 650 GPM at 100 psig upon activation.

6. The CCAS Oxidizer Holding Area (OHA) site plan is shown at Figure VII-8. The OHA is very similar to its FHA counterpart. Figure VII-9 shows the OHA trailer off-load area (left), the propellant PLU (foreground) and the RSV (background). The only major difference from the FHA is that a single 28,000 gallon RSV is provided for oxidizer bulk storage, Figure VII-10. The OHA rail car off-load terminal is at Figure VII-11.

7. Figures VII-12 and VII-13 show the CCAS Titan OHA propellant loading unit. It is identical to the FHA's PLU, except for minor pipe routing differences.

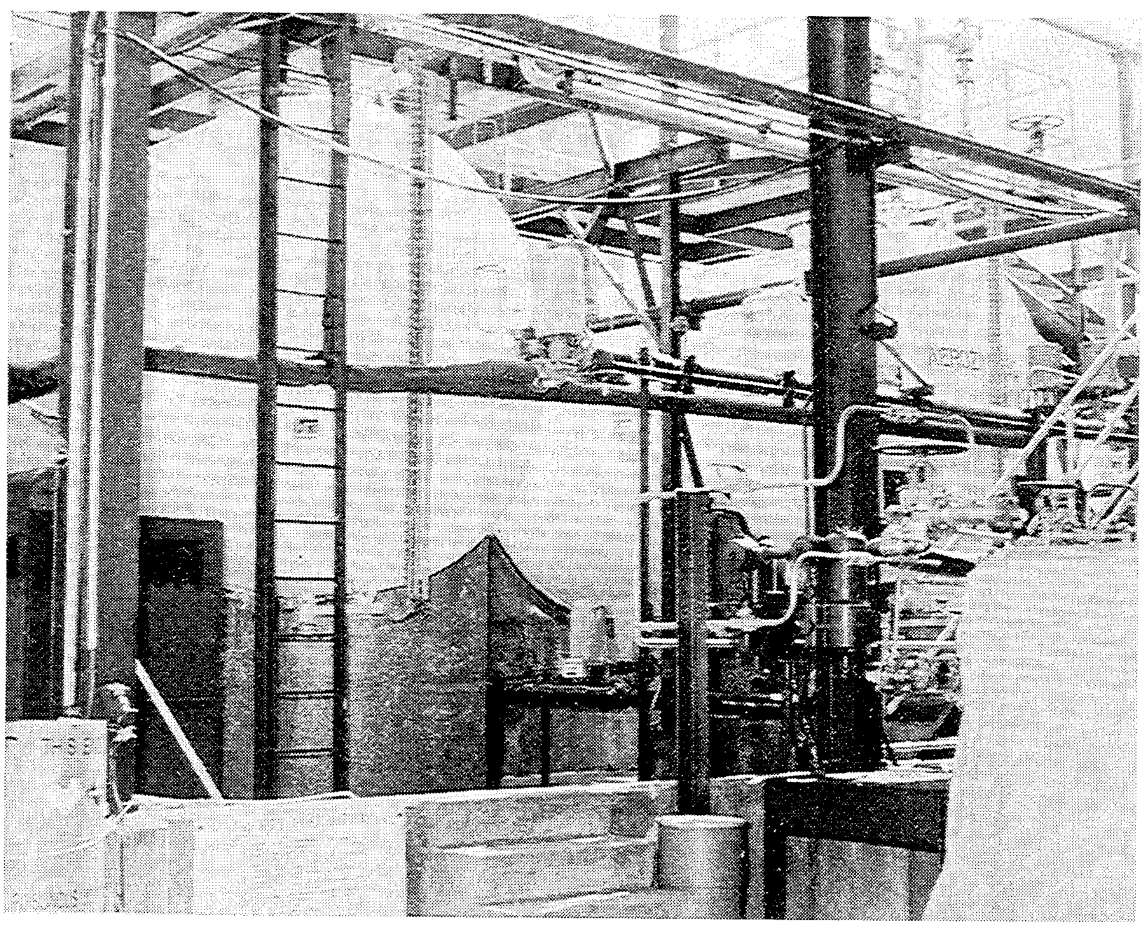


Figure VII-5. CCAS Titan Ready Storage Vessels (RSVs).

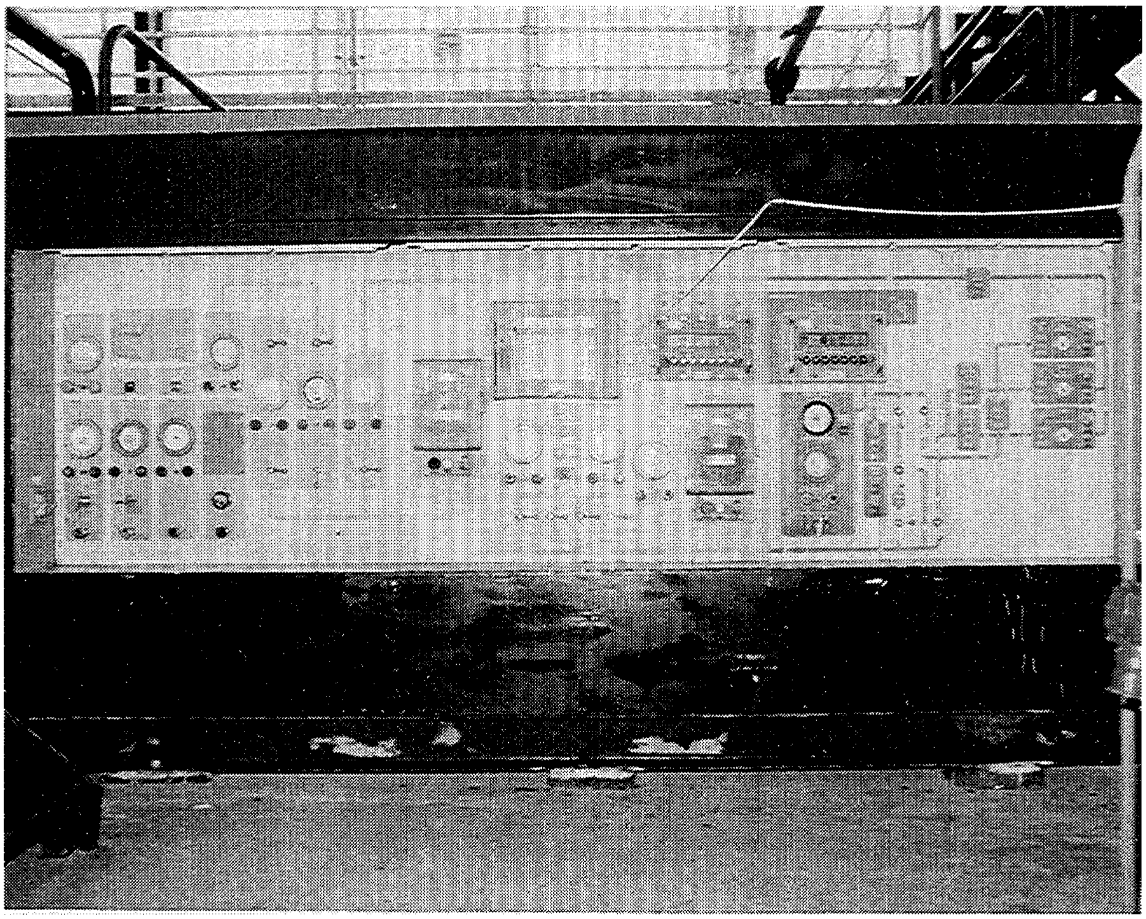


Figure VII-6. CCAS Titan FHA Propellant Loading Unit (Front View).

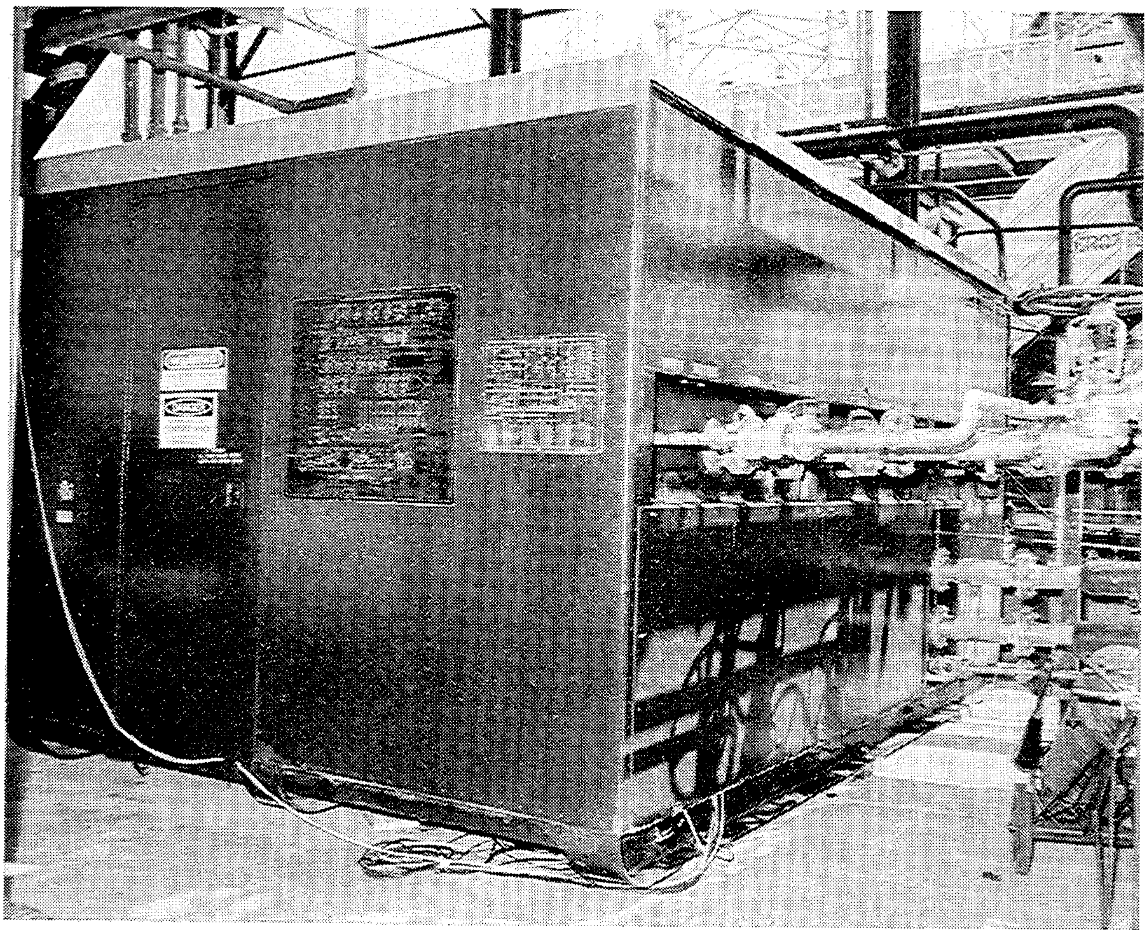


Figure VII-7. CCAS Titan FHA Propellant Loading Unit (Rear View).

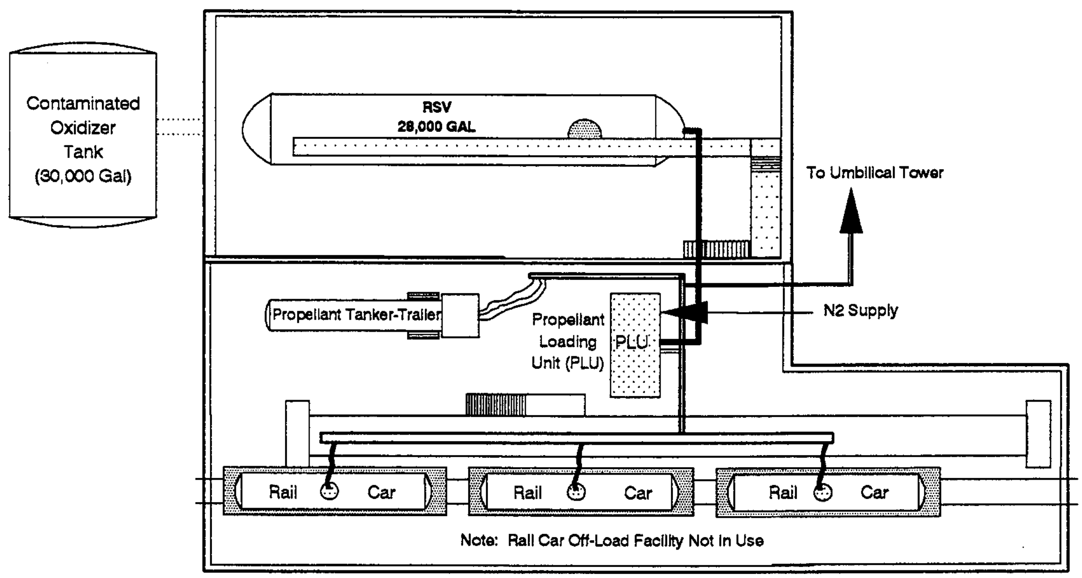


Figure VII-8. CCAS Titan Oxidizer Holding Area (OHA) Site Plan.

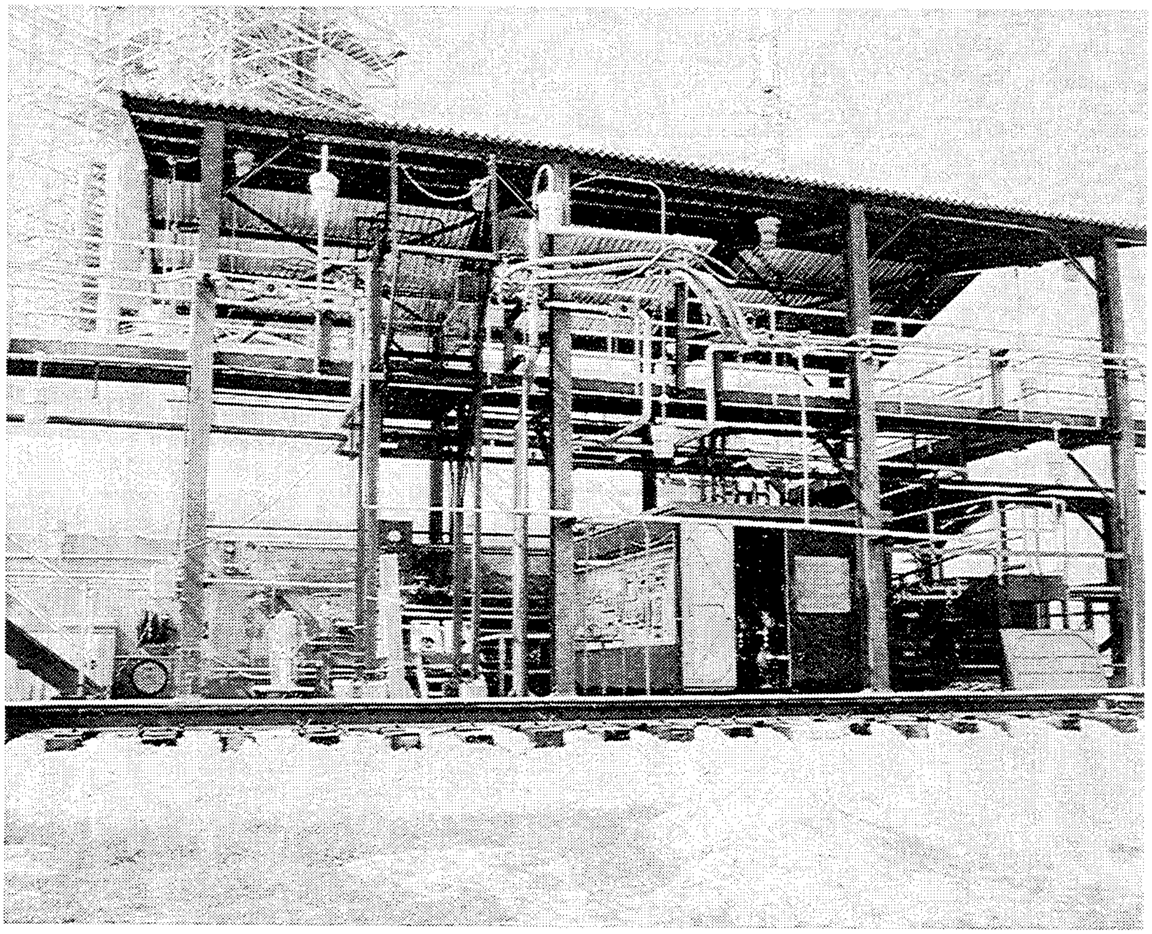


Figure VII-9. CCAS Titan Oxidizer Holding Area (OHA)

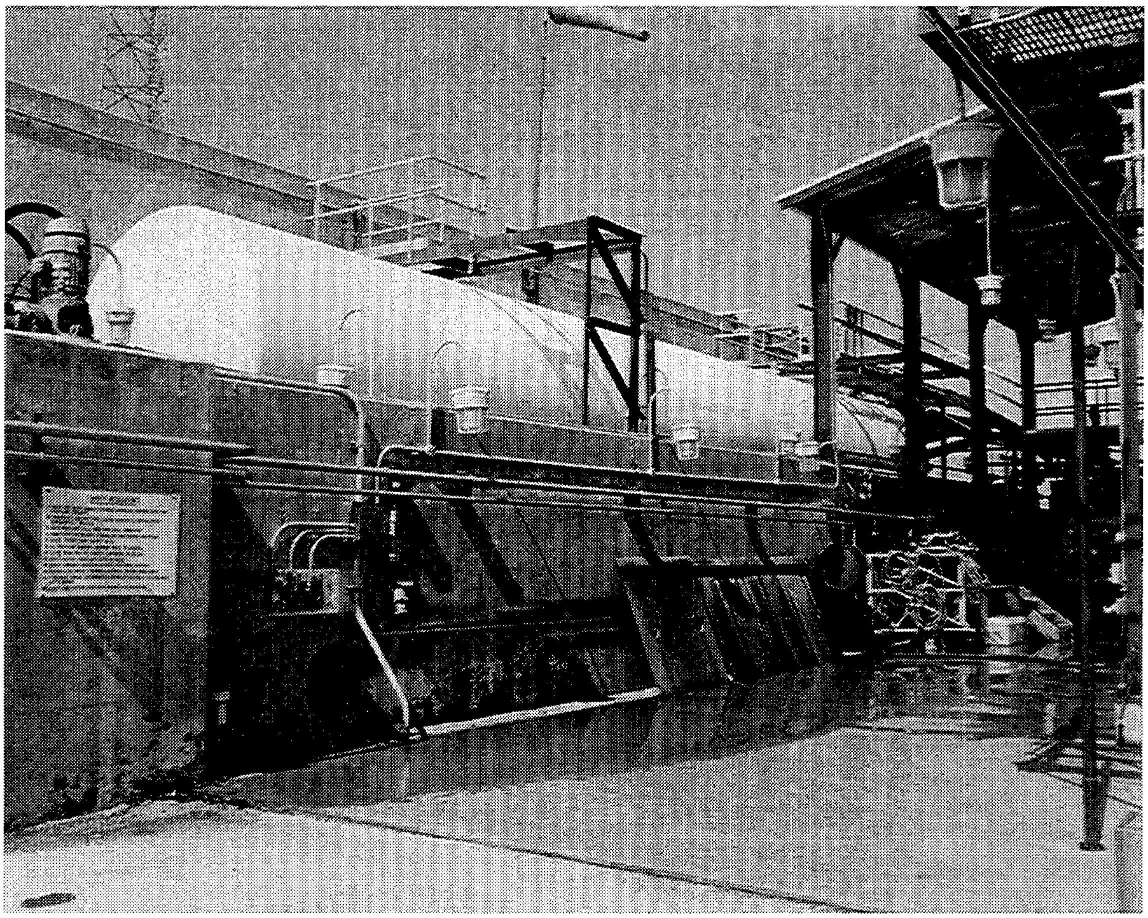


Figure VII-10. CCAS Titan OHA Ready Storage Vessel (RSV).

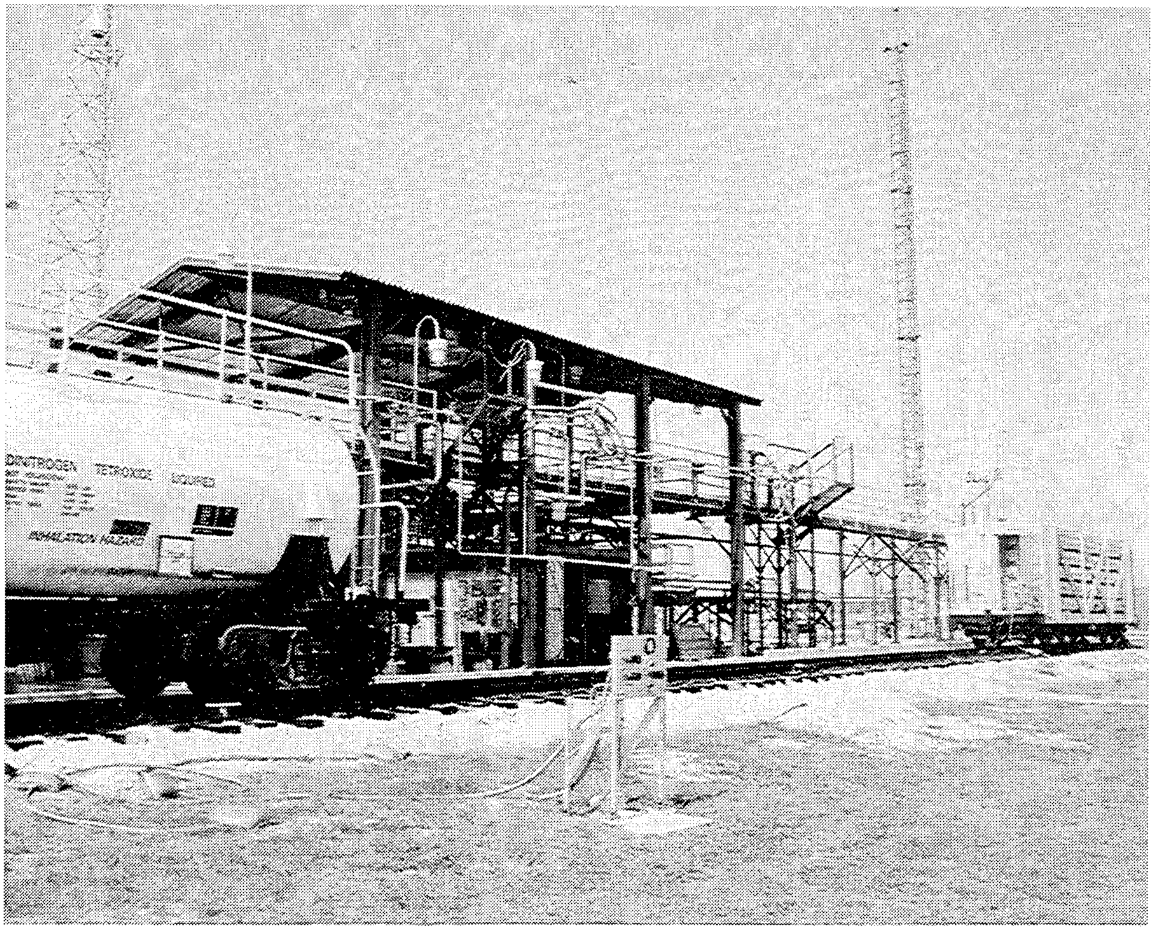


Figure VII-11. CCAS Titan OHA Rail Car Off-Load Terminal.

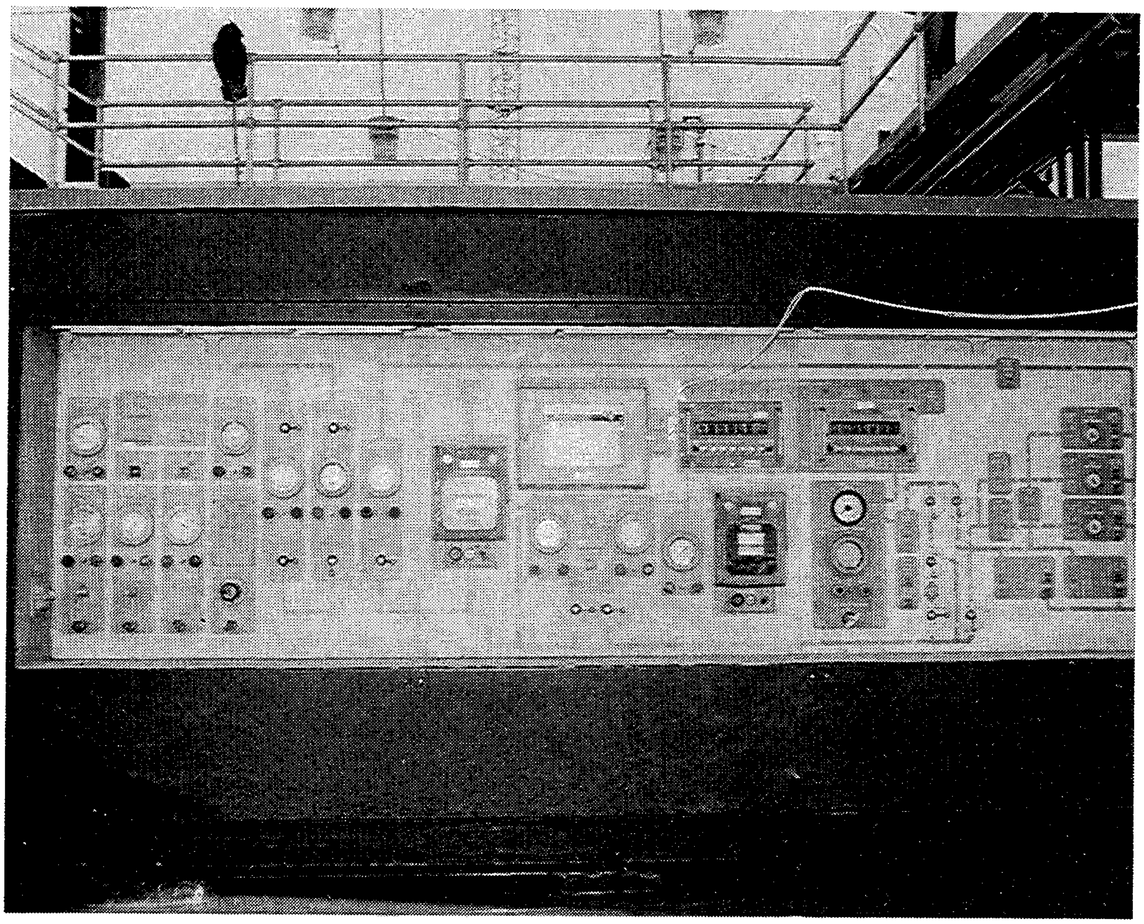


Figure VII-12. CCAS Titan OHA Propellant Loading Unit (Front View).

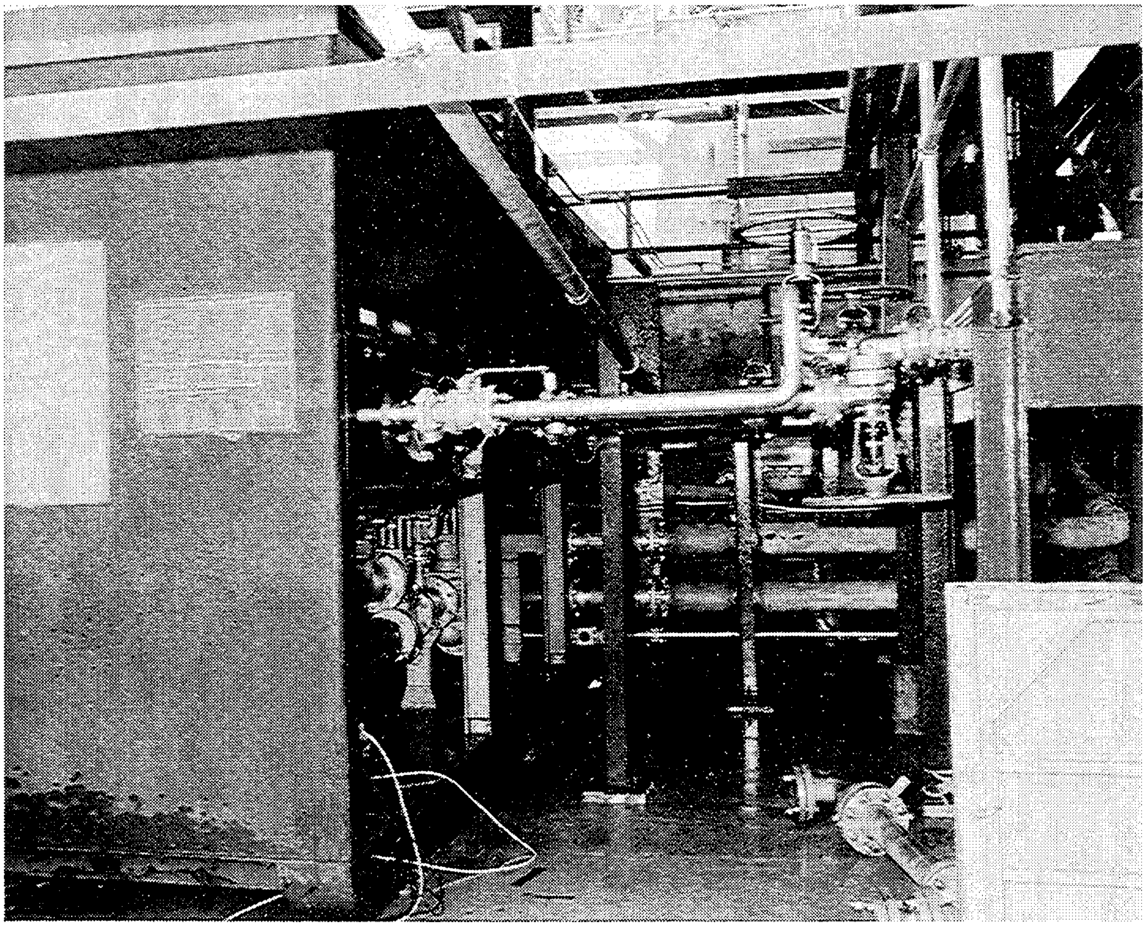


Figure VII-13. CCAS Titan OHA Propellant Loading Unit (Rear View).

E. VAFB TITAN IV FUEL AND OXIDIZER HOLDING AREAS

1. The VAFB fuel and oxidizer holding areas are capable of receiving product only from mobile tanker trailers. There are no rail car off-load capabilities, as are found at CCAS.

2. Figure VII-14 depicts the Fuel Holding Area (FHA) at SLC-4E. The RSV is a 28,000 gallon stainless steel tank. The SLC-4W FHA is similar in Plan, except there are two 15,000 RSVs, as shown at the figure. RSVs are filled from delivery trailers using nitrogen pressure.

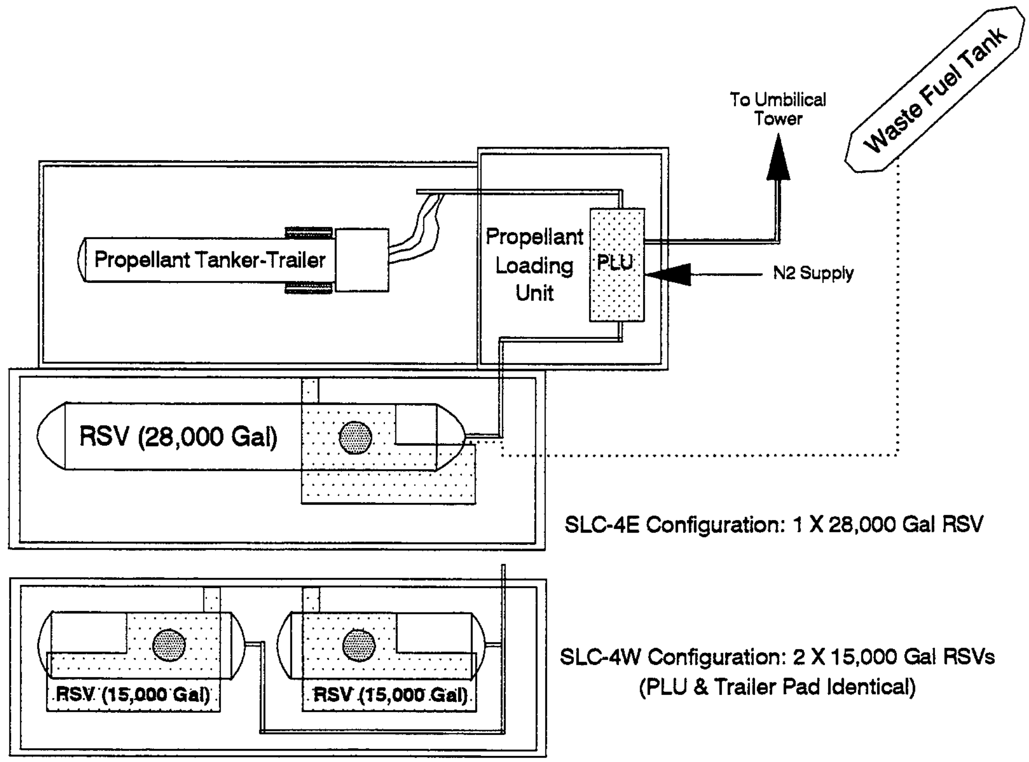


Figure VII-14. VAFB Titan Fuel Holding Area (FHA) Site Plan.

3. Fuel and oxidizer propellant loading units (PLU) are identical, except for minor differences due to different fluid properties and locations of launch vehicle fuel/oxidizer tanks. They are a fully-enclosed, skid-mounted, central propellant pumping, control and distribution system to the Titan IV launch vehicle. Major subsystems include:

a. The propellant fluid subsystem consists of an external, electrically-driven centrifugal pump, totalizing flow meters, manual flow control system, a flowmeter verification system, and other associated valves, controls and monitors. The fuel transfer pump operates at the following flow rates and Total Dynamic Head (TDH) output pressures:

- 50 GPM at 198 feet TDH
- 100 GPM at 280 feet TDH
- 200 GPM at 224 feet TDH

b. The pressurization and vent subsystem consists of control valves, piping and back pressure regulators to vent or transfer toxic vapors from each launch vehicle stage fuel tank. It provides the capability for propellant transfer by closed or open loop vent methods. The same piping and controls are also used to blanket and/or purge the entire propellant loading system.

c. The transfer nitrogen subsystem consists of pressure-regulating valves, control valves, instrumentation and piping. It reduces nitrogen pressure drawn from storage tanks and distributes all nitrogen for purging or blanketing operations.

d. The control nitrogen subsystem consists of pressure-regulating valves, control valves, instrumentation and piping to provide actuation pressures for the remote operation of valves and regulators.

e. The electrical subsystem contains all electrical components necessary for PLU operation and control. It consists of equipment to start and operate the transfer pump, monitor system status and condition, and remotely control transfer system valves required for propellant loading operations.

4. Figure VII-15 depicts the OHA site plan for SLC-4E. The RSV consists of a single 28,000 gallon stainless steel tank. The SLC-4W OHA Plan and capacity are identical.

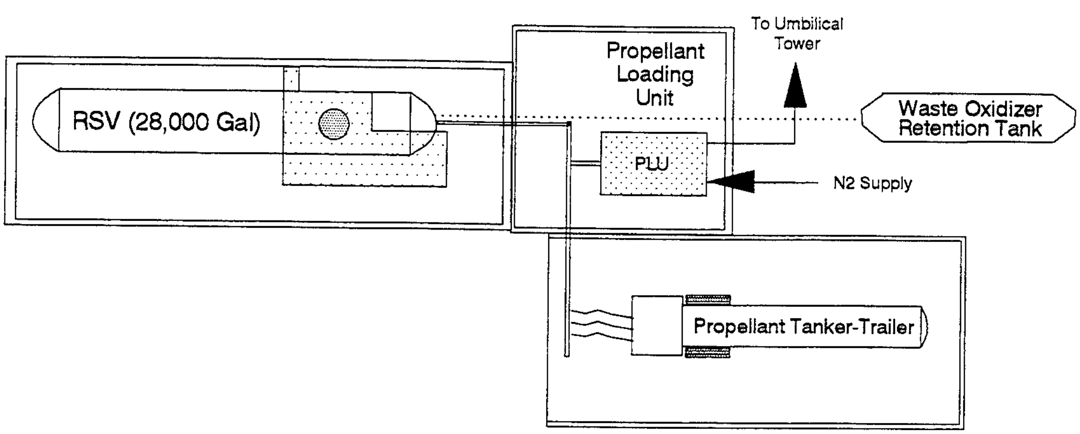


Figure VII-15. VAFB Titan Oxidizer Holding Area (OHA) Site Plan.

SECTION VIII

CCAS AND VAFB HYPERGOLIC PROPELLANT FLOW CHARTS

A. FLOW CHART RATIONALE

1. Comprehensive fire department planning and training for emergency response operations involving the accidental release of hypergolic propellants requires detailed knowledge of the potential transportation and distribution paths for each chemical product. Propellant flow charts were prepared for this purpose. They define the receiving, storage, handling, distribution and end-use paths for each hypergolic chemical used on CCAS and VAFB.

2. Flow charts identify the locations where propellants are stored, where dynamic transfer and container maintenance operations occur, and where the potential for accidents involving product release may result. In Figure VIII-1, the blocks define container locations and

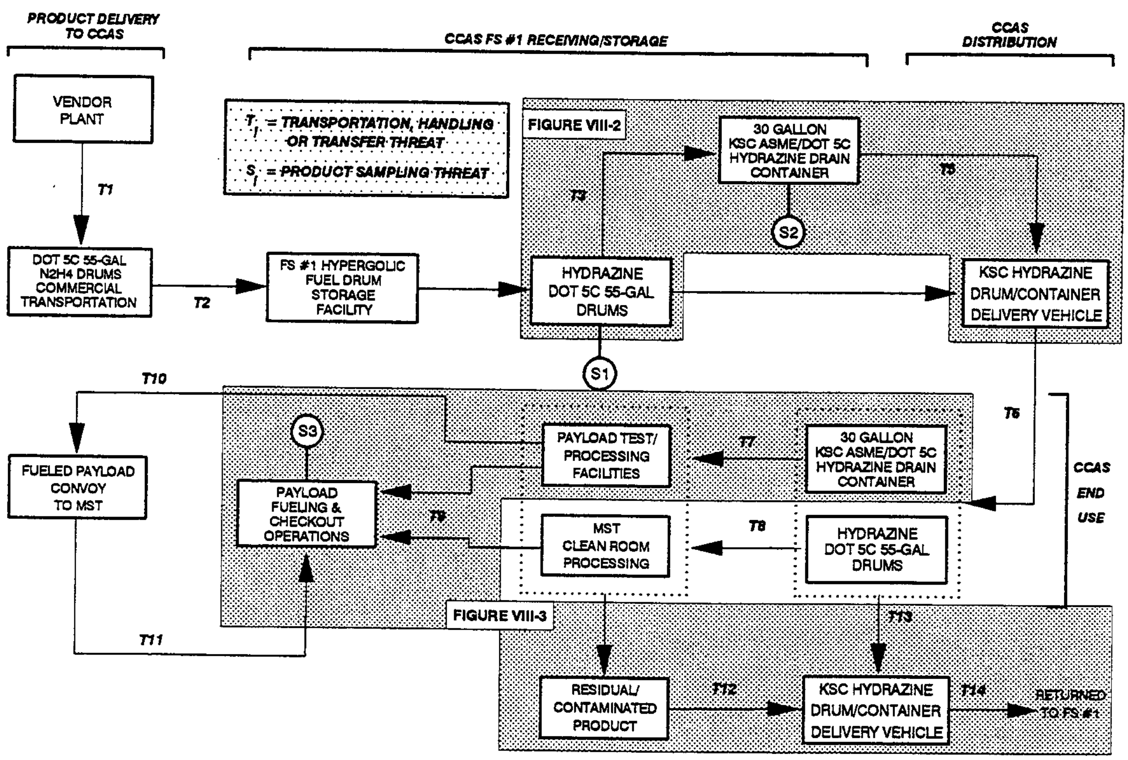


Figure VIII-1. Flow Chart Depicting Transportation, Handling, Transfer and Sampling Threat Conditions.

transportation modes. As noted in Figure VIII-1, action arrows define transfer or movement of the chemicals from one container or location to another. Potential transportation, handling or transfer accident threats, T_i, are associated with action arrow tasks. Potential container sampling accidents, S_i, also are identified. These occur at bulk or end-use storage sites.

B. FLOW CHART CHARACTERISTICS

1. Figures VIII-2 and VIII-3 how flow chart detail can be expanded to the level required for fire fighter education and training. They depict the specific propellant transfer and sampling activities associated with the shaded areas shown at Figure VIII-1.

2. Figure VIII-2 depicts several processing tasks involving 55-gallon drums of monopropellant-grade hydrazine that are conducted at the CCAS Fuel Storage Area #1.

a. All drums are delivered on vendor trucks and off-loaded at the hydrazine drum storage facility, which is an open sided steel shed and concrete floor. 55-gallon drums are sampled for purity at the storage area, as specified by the end-user's quality assurance requirements.

b. When required by the mission master schedule, drums are uploaded on to a flat bed or pickup delivery vehicle and transported to a launch complex or payload processing facility.

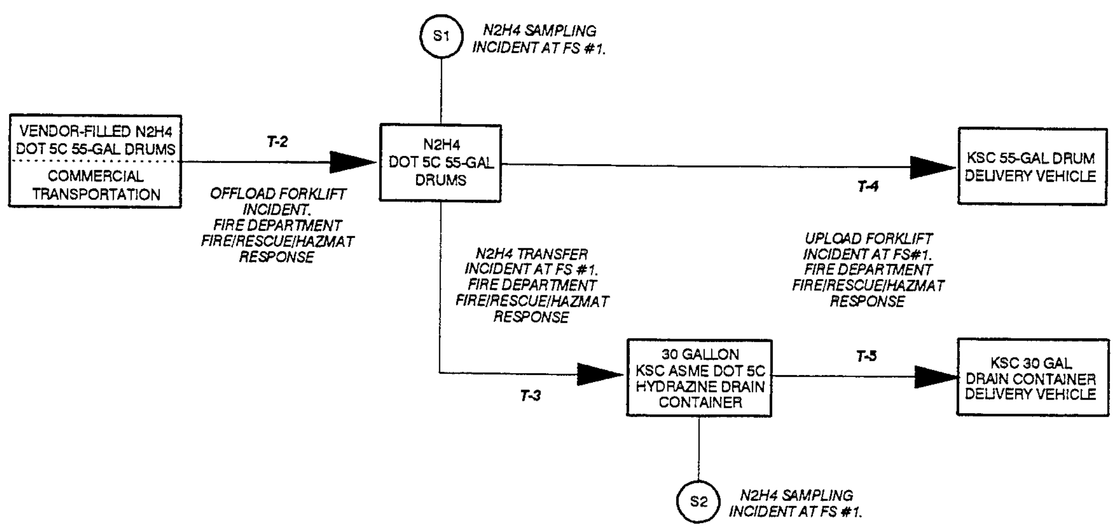


Figure VIII-2. Hydrazine Receiving and Storage Flow Chart.

c. Additionally, 55-gallon drums may be used to fill smaller, 30-gallon drain containers. These were designed by NASA and, generally, support Shuttle and Shuttle payload processing requirements. Once the hydrazine has been transferred into the drain containers, it is sampled, according to end-user requirements. Drain containers also are transported to payload and Orbiter processing facilities by flat bed or pickup truck.

d. Potential accidental release mechanisms are:

- Forklift offload or upload accident involving a dropped or punctured container.
- Accident during propellant transfer from a 55-gallon drum to a 30-gallon KSC drain container.
- Drum or drain container sampling accident.

3. Figure VIII-3 depicts the detailed product flow for hydrazine delivered either in 55-gallon drums or 30-gallon drain containers to a ground-level or elevated clean room facility for payload processing.

a. Upon arrival, drums and containers are off-loaded and stored in the facility.

b. At the appropriate schedule milestone, the drums or containers are moved to the clean room and connected to propellant transfer and conditioning units. Sampling may occur, according to payload quality assurance requirements.

c. Finally, the dynamic transfer of propellant from the container to the on-board payload fuel tank takes place.

d. Empty and partially-used containers, plus any waste hydrazine drums are then removed from the facility and returned to FSA #1.

e. Potential accidental release mechanisms that could require fire department response include: forklift unloading incidents at the processing site, an accident during movement of the container inside the processing facility or from ground level to the elevated MST clean room, during the dynamic transfer into the payload fuel tank, and during a sampling operation.

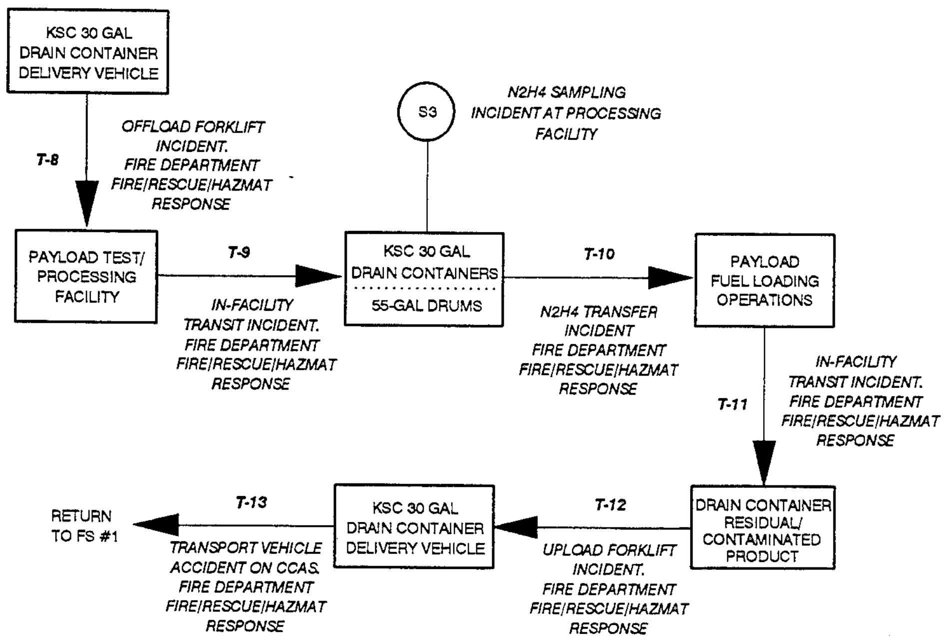


Figure VIII-3. Payload Processing Facility Hydrazine Flow Chart.

C. SPACE LAUNCH HYPERGOLIC PROPELLANT FLOW CHARTS

1. Volume II contains detailed flow charts for hydrazine, MMH and A-50 fuels, and nitrogen tetroxide oxidizer at CCAS and VAFB. They depict potential accidental release threats from propellant handling, distribution, transportation and transfer, as well as from sampling operations.

2. There are no rail cars or NASA-procured 500, 30 & 5-gallon containers used on VAFB. Additionally, there are no propellant transportation movements to Shuttle launch facilities at Vandenberg. Therefore, the VAFB flow charts will be less diverse than those depicting CCAS hypergol transportation movements to both KSC and Air Force customers. CCAS propellant-fire department interfaces also include extensive hazardous operations involving the drum-to-KSC container or KSC container-to-KSC container dynamic transfers required for Shuttle processing.

SECTION IX

CCAS AND VAFB HYPERGOLIC PROPELLANT HAZARD ANALYSIS

A. ASSUMPTIONS

1. This analysis assumed that accidental releases of hypergolic propellants on CCAS and VAFB would result from two fundamental categories of incidents involving:

- Propellant containers, bulk storage tanks or mobile tanker-trailers.
- Transfer equipment used to pump the commodities from one container to another, or into the launch vehicle and payload on-board tanks.

2. The potential locations where such accidents were most likely to occur were determined by the analysis of flow charts of the hydrazine fuels and nitrogen tetroxide stored and used on CCAS and VAFB. Flow charts define the receipt, storage and end-use distribution-histories of each hypergolic commodity.

B. DATA COLLECTION APPROACH

1. Contractor and Government-operated facilities at CCAS and VAFB were visited to determine the magnitude and relative probability of occurrence of hypergolic release incidents that could lead to fire department emergency response. Additionally, plans, policies and procedures that outline fire department standby and emergency response support for hazardous operations (HAZOPS) involving hypergolic fuels were reviewed.

2. The hazard analysis was conducted at the minimum level of detail that was appropriate to the fire department arriving at the scene of a hypergolic chemical release or fire incident. In this manner, accidental release scenarios were based on the following critical questions:

- What chemical is involved?
- What happened and where did it happen?
- Are there casualties?
- Are casualties down and where?
- How much propellant could be involved?
- How much actually was released?
- Is there a propellant fire?
- Are there collateral fires (brush, debris, structures, etc.)
- What caused the accident?

- What fire department support is required to terminate the release and safe the accident site?

3. Essential data were determined by site survey, the review of organizational operating procedures for propellant transfers, and site drawings of propellant transfer and storage systems.

4. Characterization of scenario data in this manner is essential to the responding Senior Fire Officer (SFO) at the site of a hypergolic propellant release accident at CCAS or VAFB. This information enables the SFO to select the correct level of protective equipment for fire fighters; select the proper agent for fire and/or vapor suppression; conduct and sustain suppression operations in a toxic chemical environment; rescue personnel and/or conduct HAZMAT emergency response operations for no-fire conditions. In each of these emergency operations, the SFO must consistently make the correct tactical decisions to safeguard fire department personnel while conducting suppression and rescue operations, minimize fire loss, and minimize public exposure to hazardous chemicals.

C. HAZARD ANALYSIS GENERAL APPROACH

1. Hazard analyses were conducted to determine the mechanisms and locations of accidental releases on CCAS and VAFB of hypergolic propellants that would require an emergency response by the fire department. For each accidental release scenario, the release mechanism, quantity and fire consequences (fire or no-fire) were estimated. Hazard analysis findings were used to establish the framework for justifying and quantifying increased fire department capabilities based on operational requirements.

2. Figure IX-1 identifies the general methodology used to identify and quantify potential hypergolic propellant vapor release incident scenarios. Two primary data sets were established to estimate the potential locations, mechanisms and probable outcomes of accidental releases on CCAS and VAFB:

a. Hypergolic Propellant Flow Charts

Flow charts were prepared that define the receiving, storage, handling, distribution and end use paths for each hypergolic chemical used on CCAS and VAFB. They indicate where propellants are stored on base, where and how the movement of propellant containers takes place, and where dynamic transfer hazardous operations occur. This information was used by the analysis team to estimate where and how potential accidental releases may occur. Flow

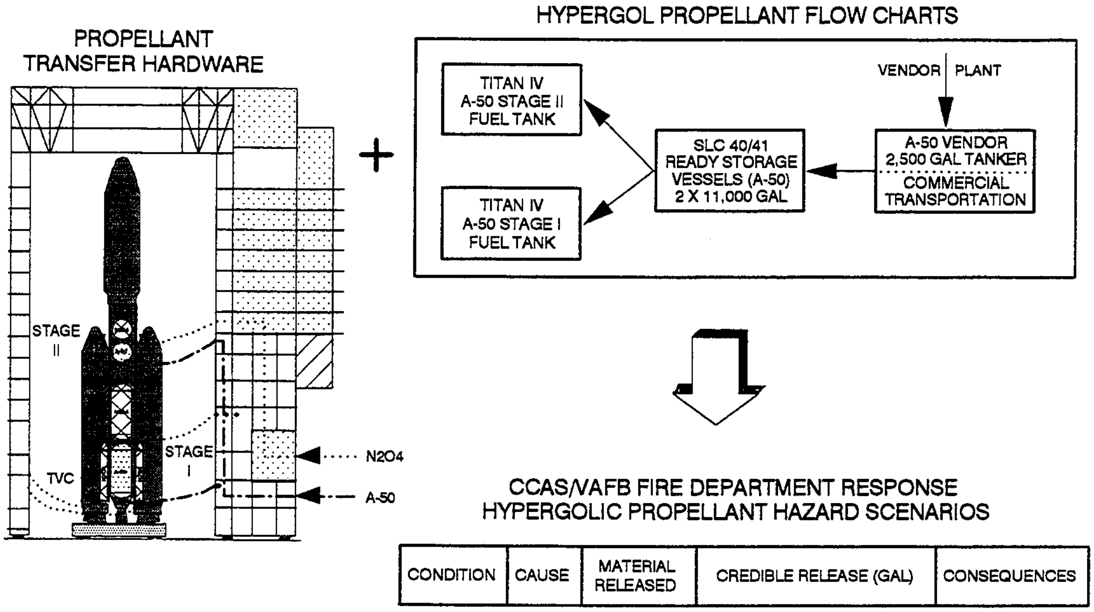


Figure IX-1. Generalized Hazard Analysis Methodology.

charts were then annotated with release threat data, as specified in Section VIII. Two primary threat mechanisms are identified:

- T_i, Transportation, handling and dynamic transfer accidents.
- S_i, Container sampling accidents.

b. Hypergolic Propellant Dynamic Transfer Hardware.

(1) Accidental propellant releases that occur during dynamic transfer operations from one container into another, generally, involve some material failure, connection problem and/or mechanical defect of the hardware components associated with the transfer system. Therefore, the mechanism (s) and probable quantities involved in the release can be estimated based on a mechanical understanding of the transfer system and the material properties and strengths of its components.

(2) Hardware and systems were characterized for each accidental propellant release threat situation identified by propellant flow charts. They are:

- Portable and fixed containers and tanks.
- Distribution hardware (pipes, valves, hoses, etc.).
- Dynamic transfer regulating equipment.

(3) Key data defined included the capacities (gallons) of the various types of containers, and the diameters and lengths of the flexible hose sections used for dynamic transfer. Similarly, the pumping capacities (gallons per minute, gpm) of the equipment panels used for fuel transfer operations were compiled.

(4) Other factors relevant to fire suppression and rescue tactics and training were estimated:

- The mechanics of the release: pool only, flowing fuel into pool, pressurized stream; and the release area size.
- The potential for fire or explosion.
- The potential for involvement of other hazardous chemicals, explosives, space launch systems/components, facilities, equipment or personnel.
- The magnitude and direction of the toxic hazard corridor (THC) generated by the propellant release.

c. The combination of flow chart and mechanical system data fields provided the analysis team with sufficient information to estimate the credible CCAS and VAFB hypergolic propellant hazard scenarios. Each scenario was designed to include the critical information needed for the planning and training of an effective fire department emergency response.

D. HAZARD ANALYSIS RESULTS

1. Nine accidental hypergolic chemical release scenarios resulting from common space launch system processing and support operations at CCAS and VAFB were identified. These scenarios represent a spectrum of generalized threats facing the CCAS and VAFB fire departments. Each can generate a fire department requirement to provide fire suppression, rescue and/or HAZMAT emergency response.

2. For each of the assumed incident/accident scenarios, the most probable release mechanisms were estimated. This information is very important to the fire department, since it defines the assumed location of the release, equipment damage and/or malfunction data, the estimated release flow rates and the potential total quantity of propellant release.

3. Each scenario consists of four major elements:

- The situation describing the circumstances and causes of the release.
- The mechanism of the release.
- The amount of propellant released.
- The expected consequences of the release, in terms of a fire or no-fire situation at the incident site.

E. HYPERGOLIC PROPELLANT ACCIDENTAL RELEASE SCENARIOS

Figure IX-2 summarizes the nine fundamental hazard scenarios assumed to result in hypergolic propellant release on CCAS and VAFB. They are listed in order from the most probable occurrence to the least probable. Detailed scenario descriptions are as follows. Scenarios also are listed in order of decreasing probability of occurrence:

1. Hypergolic Product Sampling Accident

a. Situation

(1) Fuel and oxidizer samples are drawn from 55 gallon drums, 30- and 5-gallon KSC drain containers, 500-gallon GPTUs, payload-specific ground support equipment (GSE) storage trailers, and 2,500-gallon tanker trailers at pre-determined shelf-storage intervals and prior to final end- use transfer to launch vehicle or payload on-board tanks.

(2) Hydrazine samples are placed in 1-liter glass flasks, Figure IX-3. Nitrogen tetroxide samples are placed in 1-liter stainless steel Hoke bottles, Figure IX-4. The sample apparatus for fuels, generally, consists of a hand-bulb operated plastic vacuum draw tube. Stainless steel Hoke bottles, generally, are filled by vacuum pressure.

(3) Sample operations are conducted by propellant transfer technicians donned in Self-Contained Atmospheric Protective Ensembles (SCAPE). This equipment fully encapsulates the technician and provides both vapor and splash protection against toxic chemicals. Breathing

RELEASE SITUATION	RELEASE MECHANISM	MATERIAL RELEASED	CREDIBLE RELEASE (GAL)	FIRE DEPARTMENT CONSEQUENCES
PROPELLANT SAMPLING ACCIDENT	OVERFILLED/DROPPED SAMPLE FLASK HOSE/CONNECTION LEAK	N2O4 N2H4 A-50 MMH	0.03 - 0.25	PROBABLE FUEL FIRE OXIDIZER SPILL RESPONSE
PROPELLANT CONTAINER/ TANKER MAINTENANCE ACCIDENT	UNDETECTED RESIDUAL RELEASED DURING TEAR-DOWN	N2O4 N2H4 A-50 MMH	0.25	PROBABLE FUEL FIRE OXIDIZER SPILL RESPONSE
BULK HYPERGOL STORAGE TANK LOAD OR OFFLOAD ACCIDENT/INCIDENT	CONNECTION LEAK HOSE FAILURE/LEAK MATERIAL/COMPONENT FAILURE HUMAN FACTORS	N2O4 A-50	CCAS 200 * VAFB 300 **	PROBABLE FUEL FIRE OXIDIZER SPILL RESPONSE
LAUNCH VEHICLE FHA/OHA/UT FUEL/DEFUEL ACCIDENT/INCIDENT	CONNECTION LEAK HOSE FAILURE/LEAK MATERIAL/COMPONENT FAILURE HUMAN FACTORS	N2O4 A-50	DELTA 40 TITAN 400	PROBABLE FUEL FIRE OXIDIZER SPILL RESPONSE
PAYLOAD PROCESSING FACILITY INCIDENT DURING SATELLITE FUELING/TESTING	CONNECTION LEAK HOSE FAILURE/LEAK MATERIAL/COMPONENT FAILURE HUMAN FACTORS	N2O4 N2H4 MMH	1.0	FUEL SPILL RESPONSE OXIDIZER SPILL RESPONSE
ROADWAY TRANSPORTATION VEHICLE ACCIDENT W/ PROPELLANT CONTAINERS	WELD BREAK WALL PENETRATION LEAKING CONNECTION STEM	N2O4 N2H4 A-50 MMH	7 - 55	PROBABLE FUEL FIRE OXIDIZER SPILL RESPONSE
DROPPED CONTAINER - LOADING/UNLOADING ACCIDENT	WELD BREAK WALL PENETRATION LEAKING CONNECTION STEM	N2O4 N2H4 MMH	7 - 8	PROBABLE FUEL FIRE OXIDIZER SPILL RESPONSE
ROADWAY VEHICLE ACCIDENT W/GLASS & HOKE BOTTLE SAMPLES	BROKEN GLASS BOTTLES LEAKING HOKE BOTTLE	N2O4 N2H4 A-50 MMH	0.25 - 1.0	PROBABLE FUEL FIRE OXIDIZER SPILL RESPONSE
TRANSPORTATION OR PAY-LOAD MATING ACCIDENT W/ FUELED SATELLITE	SHOCK-INDUCED LEAK FUEL TANK PENETRATION	N2O4 N2H4 MMH	9.0 - 13.5	PROBABLE FUEL FIRE OXIDIZER SPILL RESPONSE

PORTABLE PROPELLANT CONTAINER SUMMARY

- 55 GAL DRUMS (LEAST SAFE)
- KSC 5/30 GAL DOT/ASME DRAIN CONTAINERS
- SA-ALC 2,000 LB CYLINDERS
- PROGRAM-SPECIFIC GSE CARTS
- VAFB/VENDOR 5,000 GAL TANKERS
- KSC 500 GAL GPTU
- KSC/VENDOR 2,500 GAL TANKERS
- 10,000 GAL RAIL CARS (MOST SAFE)

* - 100 GPM X 2-Minutes ** - 150 GPM X 2-Minutes

Figure IX-2. CCAS and VAFB Hypergolic Propellant Accidental Release Scenario Summary.

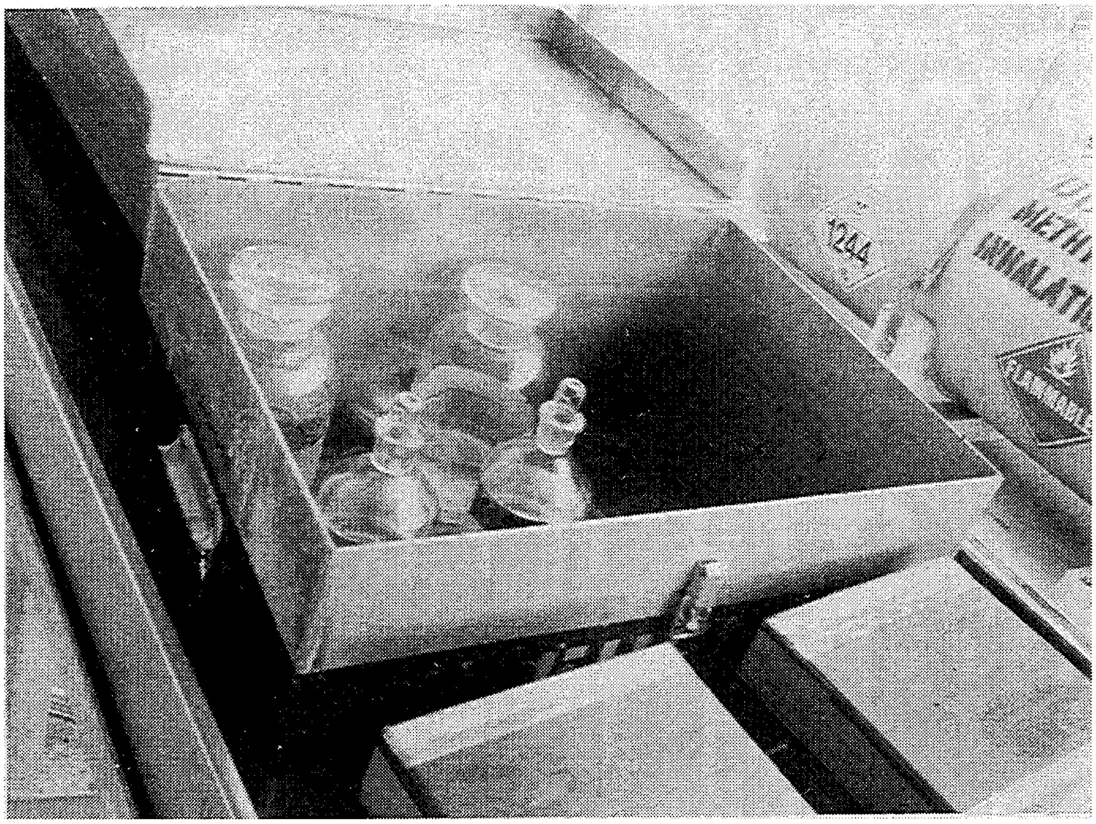


Figure IX-3. 1-Liter Fuel Glass Sample Flasks.

air is provided from a tethered central supply, or by a cryogenic air back pack. The ensemble is bulky and limits technician visibility, manual dexterity and eye-hand coordination. The potential for an improperly filled or dropped glass flask is compounded by SCAPE limitations.

b. Release Mechanisms

(1) The most probable fuel release mechanism involves an over-filled glass flask or a dropped glass flask.

(2) The most probable oxidizer release mechanism involves the improper seating of Hoke bottle draw equipment components at connection points involving stainless steel flexible hoses and rigid tube connections. Leaks in stainless steel hose sections caused by oxidizer-induced deterioration also are possible.

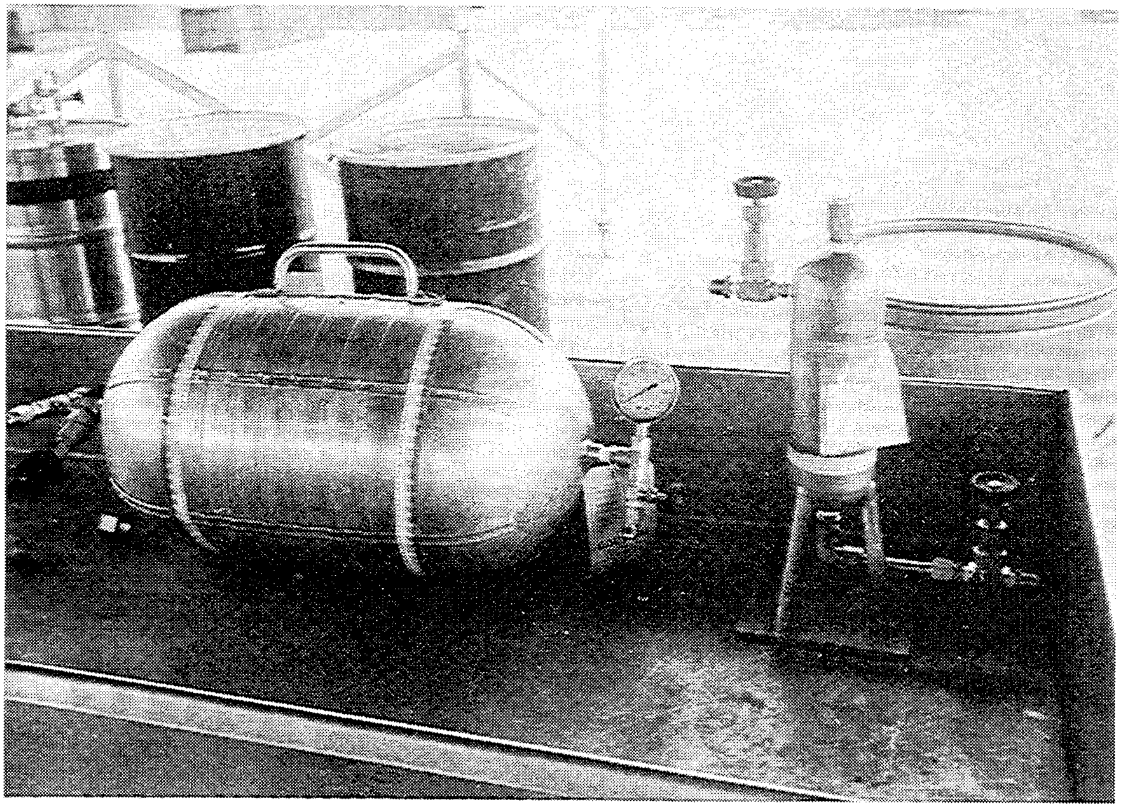


Figure IX-4. 1-Liter Hoke Bottle (Right) And Vacuum Sample Draw Vessel (Left).

(3) Hoke bottle sampling is estimated to be considerably more safe than gloved technician operations involving glass flasks and glass stop cocks (friction-only cap seals).

c. Amount of Propellant Released

Expected propellant release quantities for this scenario range from 0.03 to 0.25 gallons.

(1) Fuel Releases

A dropped 1-liter flask is estimated to result in a release of 0.25 gallons or less. A spill resulting from a glass sample bottle overfill is estimated at 0.1 gallons.

(2) Oxidizer Releases

Sample draws using nitrogen pressure and stainless steel Hoke bottles are plumbed with 1/4 to 3/8 inch diameter stainless steel flexible hoses up to 10 feet in length. The assumed release amount is 0.03 gallons for a 10-foot, 1/4 inch diameter hose. This equates to the liquid volume capacity of the hose length. The release would be caused by an improper connection or hose material failure.

d. Consequences of the Release

(1) Propellant container samples are drawn at outdoor storage facilities and inside payload processing clean rooms.

(2) Samples from drums, drain containers, GPTUs and mobile trailers are drawn outdoors at the CCAS Fuel Storage Area #1 (FSA #1) or at the VAFB Hypergolic Storage Facility (HSF). Containers and trailers are positioned, primarily, on sloped concrete slabs to contain any accidental release. The potential for propellant contact with metal oxides, dirt, dust or natural vegetation, resulting in fire initiation is high. Additionally, spill surface areas compared to the quantity of chemical release are estimated to be large. This increases the potential for spill spontaneous ignition from the heat generated by evaporation.

(a) A fire condition is assumed to result from accidental outdoor releases during AH, MMH or A-50 sampling operations. Exterior fuel spills are assumed to contact a metal oxide or dry vegetation source or to be absorbed by dust and/or fine-grained debris on the ground, and to spontaneously ignite.

(b) Since the amount of fuel released is small, the total quantity involved in the fire would be significantly reduced by evaporation before ignition occurs. Therefore, a very short duration fire (30-60 seconds) is estimated to result.

(c) Hydrazine fires also would produce extremely toxic combustion products. Once extinguished, any released or residual hydrazine at the incident site would continue to off-gas highly toxic vapors.

(3) Sampling operations also may be conducted inside payload processing clean room facilities. In these cases, drums, containers and propellant transfer, conditioning and sampling apparatus are placed inside stainless steel drip pans. Additionally, exposed metals are stainless steel. Dust and dirt particles are virtually non-existent. Therefore hydrazine release incidents that occur

during operations conducted inside clean room facilities are assumed not to cause a fire condition.

(4) Accidental releases of nitrogen tetroxide during sampling operations conducted at outside storage areas or inside clean rooms are assumed to produce only a limited area, short duration toxic vapor threat.

2. Accidental Release During Propellant Container or Tanker-Trailer Maintenance Operation

a. Situation

Tanker trailers and portable containers require periodic maintenance and inspection. Residual hypergolic propellants are purged from containers and ullage cavities by nitrogen pressure and/or vacuum. A small, undetected, residual amount of fluid can remain in the container or ullage following the purge operation. Initiation of container tear-down would result in a small propellant release. Container maintenance operations are conducted by technicians donned in SCAPE ensembles, as previously described. This protective equipment limits the technician's visibility, manual dexterity and eye-hand coordination.

b. Release Mechanisms

Propellant is released when a container access port or penetration component is removed. This causes the release of toxic vapors from within the container cavity. The gravity flow of the propellant on to the pavement below, also may result.

c. Amount of Propellant Released

The expected propellant release quantity for this scenario is assumed to be 0.25 gallons.

d. Consequences of the Release

(1) Container maintenance operations are usually conducted at an outdoors location at the CCAS FSA #1 and at the VAFB HSF. Containers and tanker trailers, normally, are positioned on sloped concrete slabs to contain any accidental release. The potential for propellant contact with metal oxides, dirt, dust or natural vegetation, resulting in fire initiation is high. Additionally, spill surface areas compared to the quantity of chemical release are estimated to be large. This increases the potential for spill spontaneous ignition from the heat of evaporation.

(a) A fire condition is assumed to result from accidental outdoor releases during AH, MMH or A-50 container or trailer maintenance tasks. Exterior fuel spills are assumed to contact a metal oxide or dry vegetation source or to be absorbed by dust and/or fine-grained debris on the ground, and to spontaneously ignite.

(b) Since the amount of fuel released is small the total quantity involved in the fire would be significantly reduced by evaporation before ignition occurs. Therefore, a very short duration fire (30-60 seconds) is estimated to result.

(c) Because of the small amount of chemical spilled and limited fire area, container maintenance-generated fires should be extinguished by trained technicians in the area. Personnel must be attired in SCAPE, and should use hand-held water or dry chemical fire extinguishers. The fire department must be notified to ensure the incident is investigated and the area is secured and cleaned up. Joint operations procedures between CCAS and VAFB fire departments and the fuel storage area contractors are recommended to define specific fire notification and emergency response interfaces.

(d) Maintenance accidents involving significantly larger quantities of hydrazine, larger fire areas and/or casualties require immediate fire department notification and response.

(e) Hydrazine fires also would produce extremely toxic combustion products. Once extinguished, any released or residual hydrazine at the incident site would continue to off-gas highly toxic vapors.

(2) Accidental releases of nitrogen tetroxide during sampling operations located at outside storage areas or inside clean rooms are assumed to produce only a limited area, short duration toxic vapor threat.

(3) Hydrazine fires that result from container maintenance releases will be very difficult to detect, since hydrazine burns with virtually no recognizable color or smoke. The CCAS technicians involved in actual fire incidents were unaware of the release until they noticed the discoloration and melting of their gloves.

3. Accidental Release During A Dynamic Transfer Operation At A Bulk Storage Facility

a. Situation

(1) Ready storage vessels (RSVs) for the bulk storage of A-50 and N_2O_4 are located at CCAS and VAFB

Titan launch site fuel and oxidizer holding areas (FHA/OHA). At CCAS, these tanks may be filled by tanker-trailers or from railroad tank cars. At VAFB, RSVs are filled by tanker-trailers, only.

(2) The Hypergolic Storage Facility (HSF) at VAFB also contains bulk A-50 and nitrogen tetroxide storage tanks. These are filled from mobile tanker-trailer units. Conversely, mobile tankers are filled from HSF bulk storage tanks for deliveries to launch complex users.

(3) At CCAS, bulk A-50 and N_2O_4 are stored at Fuel Storage Area #1 in 2,500-gallon tanker-trailer units. Propellants may be transferred from vendor tankers to KSC-owned tankers for storage, or stored in vendor tankers prior to delivery to the launch sites.

(4) Propellants are off-loaded from mobile tanker trailers into the fixed bulk storage facility distribution system. Connections from mobile to fixed systems are via flexible stainless steel hose sections. Transfer pressure is supplied by a fixed or mobile nitrogen source.

(5) Propellant transfer operations are plumbed and conducted by engineers and technicians donned in SCAPE ensembles. As previously described, this protective equipment limits occupant visibility, manual dexterity and eye-hand coordination.

b. Release Mechanisms

(1) The improper seating of stainless steel hose disconnect hardware with additional hose lengths or the fixed connection points of the mobile tanker or bulk storage facility.

(2) Leaks through a breach in a stainless steel hose section or in a fixed distribution system component. These can be caused by temperature stresses and displacements, thermal fatigue or reactive chemical - induced deterioration and subsequent material failure under transfer pressures.

(3) Deterioration, temperature-induced displacements, material fatigue, cathodic erosion, and/or improper maintenance of a propellant transfer system component, such as a valve, flowmeter, pipe or connection fitting that results in a material failure or joint separation.

(4) Human factors. Failure to comply with official procedures could result in the routing and transfer of propellants to a non-authorized destination. Examples include vent pipes or open sump areas.

c. Amount of Propellant Released

(1) Propellant release mechanisms are assumed to occur while the transfer system is under pressure and the dynamic transfer is underway. Therefore, a leak or propellant mis-routing will sustain itself until the problem is identified and the leak point is isolated or plugged.

(2) The assumed release quantity is the volume of product transferred by the propellant transfer unit (PTU) at its normal operating flow rate (gpm), before the problem can be identified and the flow can be terminated.

(3) The time to identify and isolate a material failure or system set-up error that results in a product release is estimated at 2 minutes. This reaction time accounts for the propellant loading crew being fully-encapsulated in their protective SCAPE equipment, which limits awareness of surrounding conditions, vision and manual dexterity.

(4) Accordingly, the estimated release quantity is the product of the PTU flow rate times 2 minutes.

(5) PTUs at bulk storage facilities are, normally, operated flow rates of from 50 to 100 gpm. With a 2-minute leak termination response time, the estimated propellant release quantity could be from 100- to 200-gallons.

d. Consequences of the Release

(1) A fire is assumed to result from an A-50 release of this magnitude. Propellant transfer operations, normally, are conducted on sloped concrete surfaces with drains leading to a sump, catch basin or holding tank. While the spill may be contained on the concrete, the rough surface is generally dirty and may trap metal oxide (iron rust) or dust particles that would cause the A-50 to spontaneously ignite.

(2) An A-50 fire involving 100- to 200-gallons would be very intense. This amount of fuel could cover about 2,600 square feet on a flat, continuous surface. Spill areas on sloped pavements will be considerably smaller. Large amounts of toxic combustion products would be released from the fuel surface.

(3) Accidents involving the release of N_2O_4 are not estimated to result in a fire condition at the accident site.

(4) Accidental releases of N_2O_4 and A-50 will result in a large release of toxic chemical vapors. A rough order of magnitude estimate of the toxic hazard corridor (THC) for a 200 gallon release of A-50 is 14,600-feet downwind. For N_2O_4, the THC is about 8,350-feet.

(a) These estimates were computed using the one-dimensional Ocean Breeze/Dry Gulch Equation for typical CCAS daylight conditions, and an assumed peak A-50 concentration of 0.24 ppm and a N_2O_4 peak concentration of 2.00 ppm.

(b) The equation uses an evaporation rate estimate for both fuels and oxidizer. This factor was used to estimate spill area evaporation times based on spill depth. Accordingly, a 0.1 inch thick spill pond of A-50 is estimated to evaporate in 26 minutes. A 0.1 inch thick nitrogen tetroxide spill pond would evaporate in about 5 minutes.

(5) Both a fire or vapor threat condition resulting from a 100- to 200-gallon propellant spill at a bulk storage facility would require a major fire suppression and HAZMAT emergency response operation. The potential also exists for injuries to propellant transfer technicians. Fire department rescue operations may be required.

(6) Any fire department entry into a hazardous vapor threat area for fire suppression, rescue or HAZMAT spill containment operations will require fire fighters to be donned in fully-encapsulated, Level A protective equipment, as defined by OSHA 29 CFR 1910.120 (q), *Emergency response to hazardous substance releases*, and NFPA 471, *Responding To Hazardous Materials Incidents*.

4. Propellant Release Incident During Launch Vehicle Fueling or De-Fueling Operations

a. Situation

(1) Hypergolic fuel and oxidizer tanks on Delta and Titan lift vehicles are filled during the pre-launch sequence. Under long-duration launch aborts, defueling of tanks is required because of venting losses and/or safety considerations.

(2) Delta hypergolic propellant tanks are located in Stage II, only. Titan Stage I and Stage II tanks contain A-50 and oxidizer. Additionally, the two Titan IV solid rocket motors each are configured with a thrust vector

control (TVC) system that is fueled by nitrogen tetroxide. TVC oxidizer tanks are mounted on the side of each solid rocket motor column.

(3) At Delta and Titan launch towers, fuel and oxidizer are fed from fixed piping systems to the launch vehicle tank by means of flexible stainless steel hose sections. Delta transfer pressure at CCAS is supplied by a fixed nitrogen source, while propellants at VAFB Delta facilities are transferred by helium pressure.

(4) At CCAS and VAFB Titan launch facilities, propellants are transferred from RSVs located in the Fuel and Oxidizer Holding Areas (FHA/OHA) by centrifugal pumps through fixed distribution systems.

(5) Bulk fuel for Delta vehicles at CCAS and VAFB is provided by a 2,500 gallon tanker trailer connected to the launch tower propellant distribution system by stainless steel flexible hose lengths. The propellant transfer unit (PTU) is located on the mobile tanker-trailer units.

(6) Propellant transfer operations are plumbed and conducted by engineers and technicians donned in SCAPE ensembles. As previously described, this protective equipment limits occupant visibility, manual dexterity and eye-hand coordination.

b. Release Mechanisms

(1) The improper seating of stainless steel hose disconnect hardware with additional hose lengths or the fixed connection points of the mobile tanker or bulk storage facility.

(2) Leaks through a breach in a stainless steel hose section or in a fixed distribution system component. These can be caused by temperature stresses and displacements, thermal fatigue or reactive chemical - induced deterioration and subsequent material failure under transfer pressures.

(3) Deterioration, temperature-induced displacements, material fatigue, cathodic erosion, and/or improper maintenance of a propellant transfer system component, such as a valve, flowmeter, pipe or connection fitting that results in a material failure or joint separation.

(4) Human factors. Failure to comply with official procedures could result in the routing and transfer of propellants to a non-authorized destination. Examples include vent pipes or open sump areas.

c. Amount of Propellant Released

(1) Propellant release mechanisms are assumed to occur while the transfer system is under pressure and the dynamic transfer is underway. Therefore, a leak or propellant mis-routing will sustain itself until the problem is identified and the leak point is isolated or plugged.

(2) The assumed release quantity is the volume of product transferred by the propellant transfer unit (PTU) at its normal operating flow rate (gpm), before the problem can be identified and the flow can be terminated.

(3) The time to identify and isolate a material failure or system set-up error that results in a product release is estimated at 2 minutes. This reaction time accounts for the propellant loading crew being fully-encapsulated in their protective SCAPE equipment, which limits awareness of surrounding conditions, vision and manual dexterity.

(4) Accordingly, the estimated release quantity is the product of the PTU flow rate times 2 minutes.

(5) PTU average flow rates and estimated release quantities for lift vehicle fueling operations are defined in Table IX-1.

Table IX-1. Estimated Launch Vehicle Fueling Accidental Release Quantities.

Lift Vehicle Propellant Transfer Operation	**PTU Rate (gpm)**	**Release Quantity (Gallons)**
Delta Stage II	20	40
Titan Stage 0 (TVC)	120	240
Titan Stage I	200	400
Titan Stage II	100	200

d. Consequences of the Release

(1) A fire condition is assumed to result from a pressurized release of A-50 during fueling operations. Spontaneous ignition is assumed from the heat of friction of the pressurized release and the fine spray that is produced. It is assumed that the pressurized leak will sustain the fire until the fault area is identified and isolated.

(2) In the event that a fire did not occur at the launch tower release point, the fuel would cascade down the tower to lower elevations. Some quantity of propellant would evaporate in the strong winds usually found at CCAS and VAFB launch sites, some would be trapped on floors, and some would fall to the pavement below.

(3) It is assumed that some of these released liquid or vapors will contact an oxide or debris source, or a hot metal surface to cause the fuel to spontaneously ignite.

(4) Accidental releases of N_2O_4 or A-50 that did not involve a fire situation would result in a large release of toxic vapors. A rough order of magnitude estimate of the toxic hazard corridor (THC) for a 400 gallon release of A-50 is 20,000-feet. For N_2O_4, the THC is about 12,000-feet.

(a) These estimates were computed using the one-dimensional Ocean Breeze/Dry Gulch Equation for typical CCAS daylight conditions, and an assumed peak A-50 concentration of 0.24 ppm and a N_2O_4 peak concentration of 2.00 ppm.

(b) The equation uses an evaporation rate estimate for both fuels and oxidizer. This factor was used to estimate spill area evaporation times based on spill depth. Accordingly, a 0.1 inch thick spill pond of A-50 is estimated to evaporate in 26 minutes. A 0.1 inch thick nitrogen tetroxide spill pond would evaporate in about 5 minutes.

(5) Both a fire or vapor threat condition resulting from a 400-gallon propellant spill during a lift vehicle fuel or defuel operation would require a major fire suppression and HAZMAT emergency response operation. The potential also exists for injuries to propellant transfer technicians. Fire department rescue operations may be required.

(6) Any fire department entry into a hazardous vapor threat area for fire suppression, rescue or HAZMAT spill containment operations will require fire fighters to be donned in fully-encapsulated, Level A protective equipment, as defined by OSHA 29 CFR 1910.120 (q), *Emergency response to hazardous substance releases*, and NFPA 471, *Responding To Hazardous Materials Incidents*.

5. Accidental Release During Propellant Transfer Operations In Payload Processing Facility Clean Rooms

a. Situation

(1) Satellite fueling may take place either in ground-level clean room facilities or in Mobile Service Tower (MST) clean rooms after the payload has been mated to the launch vehicle. Centaur or other upper stage Reaction Control System (RCS) fuel tanks also are filled from MST clean rooms.

(2) For most satellite fueling operations conducted in ground-level or launch tower clean rooms, 55-gallon drums, KSC 30- and 5-gallon drain containers, or a payload-specific fuel cart are prepositioned inside the clean room. Active drums are placed on a scale, which is located in a drip pan. Fill, vent and drain lines are connected to a portable, vacuum pump-operated service panel that also is set inside a drip pan. The fill line is routed to a fill and service panel (in a drip pan) for final flow control, temperature conditioning or sampling, and then to the payload fuel tank.

(3) Connections between all components are by flexible stainless steel hose sections. Drip pans are placed under each hose run, where feasible. Propellant loading technicians and system engineers, and a safety officer are present in the clean room during set-up, system connection and propellant transfer operations.

(4) Payload fueling hardware is plumbed and transfer operations are conducted by engineers and technicians donned in SCAPE ensembles. As previously described, this protective equipment limits occupant visibility, manual dexterity and eye-hand coordination.

b. Release Mechanisms

(1) The improper seating of stainless steel hose disconnect hardware with additional hose lengths or the fixed connection points of the mobile tanker or bulk storage facility.

(2) Leaks through a breach in a stainless steel hose section or in a fixed distribution system component. These can be caused by temperature stresses and displacements, thermal fatigue or reactive chemical - induced deterioration and subsequent material failure under transfer pressures.

(3) Deterioration, temperature-induced displacements, material fatigue, cathodic erosion, and/or improper maintenance of a propellant transfer system

component, such as a valve, flowmeter, pipe or connection fitting that results in a material failure or joint separation.

(4) Human factors. Failure to comply with official procedures could result in the routing and transfer of propellants to a non-authorized destination. Examples include vent pipes or clean room open areas.

c. Amount of Propellant Released

(1) Propellant release mechanisms are assumed to occur while the transfer system is under pressure and the dynamic transfer is underway. Therefore, a leak or propellant mis-routing will sustain itself until the problem is identified and the leak point is isolated or plugged.

(2) The assumed release quantity is the volume of product transferred by the propellant transfer unit (PTU) at its normal operating flow rate (gpm), before the problem can be identified and the flow can be terminated.

(3) The time to identify and isolate a material failure or system set-up error that results in a product release is estimated at 2 minutes. This reaction time accounts for the propellant loading crew being fully-encapsulated in their protective SCAPE equipment, which limits awareness of surrounding conditions, vision and manual dexterity.

(4) Payload fueling operations, normally, are conducted at a 0.5 gpm flow rate. Accordingly, the estimated release quantity is the product of the PTU flow rate times 2 minutes, or 1.0-gallon.

d. Consequences of the Release

(1) Hydrazine and MMH releases in clean room facilities are assumed to produce only a toxic vapor and/or a liquid contact hazard. The ignition of hydrazine vapors is assumed not to occur. This vapor hazard-only rationale for the fuels is based on the following factors:

(a) Clean rooms are inherently free from the dust and debris that could cause hydrazines to spontaneously ignite.

(b) Metal surfaces that could contact hydrazine spills or vapors are constructed of stainless steel. These include scaffolds, equipment support stands/cabinets, furniture items and floor sump grates. Therefore, the presence an oxide source for hypergolic ignition is not probable.

(c) Clean room volumes are very large, compared to the estimated credible release quantity of fuel. Air handling equipment provides for high air-mixing and exchange rates. Additionally, portable aspirators and emergency exhaust fans are installed to rapidly dissipate and remove vapors from a suspected leak point. Therefore, vapors from accidental clean room releases are assumed to remain below explosive concentrations. The lower explosive limit (LEL) air for monomeythlhydrazine is 2.5% by volume in and 4.7% for anhydrous hydrazine.

(d) Propellant interface panels, transfer lines and loading/conditioning carts are wrapped in non-reacting material scuppers to contain small releases of vapors or liquids. A spill tarp is placed around the vehicle-floor interface to prevent spill loss to lower MST levels.

(e) Wherever possible, stainless steel drip pans are placed under mobile transfer equipment, transfer lines and hypergol drums and containers.

(f) Hypergolic propellant transfer operations are conducted by highly trained and knowledgeable personnel.

- A Safety representative is present in the clean room during all hazardous operations.
- Rigorous, written procedures are followed and controlled from the launch control center.
- Usually, there are from 4 to 6 personnel in the clean room during propellant transfer. Up to six sets of eyes and hands are available to detect a leak, and to isolate and terminate it.
- Propellant transfer personnel are trained to perform emergency mop and sop operations to localize the release area and neutralize the spill residual.

(g) All connections and transfer lines are pressure-tested prior to propellant transfer. Connections and hose runs are leak-checked with hand-held vapor detectors during pressure checks and product flow operations. Some clean rooms contain fixed vapor detection systems.

(2) Clean room hydrazine and MMH fires are not considered to be credible by this analysis. However, they are not totally improbable during payload fueling or defueling operations. These are conducted under pressure, and an atomized spray release could cause spontaneous ignition. Such a fire would be extremely difficult to detect, because of the colorless and smokeless signature of a hydrazine fire. For this reason, a hydrazine flame detection system would be a significant safety enhancement for CCAS and VAFB clean rooms.

(3) In summary, propellant release incidents in clean rooms are expected to result in small spill quantities that are contained in scuppers or stainless steel drip pans. Vapors are assumed to be evacuated by hand-held aspirators or emergency vent systems. Ignition of hydrazine-family fuels is not assumed to occur. Clean room propellant transfer personnel are donned in SCAPE protective ensembles, and trained to deal with emergency response to mechanical malfunctions or material failures resulting in an unexpected fuel or oxidizer release.

(4) Oxidizer system accidents during payload processing operations will result in a 1-gallon release and toxic vapor threat, as described for fuels. It is assumed that the release will be contained and cleaned up by the technicians involved in the dynamic transfer operation.

6. Roadway Transportation Vehicle Accident Involving Hypergolic Propellant Containers or Tanker-Trailers

a. Situation

(1) Hypergolic propellants are delivered to CCAS and VAFB in drums, pressurized cylinders and in tanker trailers via on- and off-base road networks. At CCAS, these products are further re-packaged into 30- and 5-gallon drain containers and 500-gallon GPTUs for storage and/or delivery to USAF and NASA customers. KSC GPTUs are transported on special, impact-resistant, stainless steel safety trailers. Large quantities of A-50 and N_2O_4 are delivered from CCAS and VAFB storage areas to launch sites in NASA-designed 2,500-gallon tanker trailers.

(2) This scenario assumes that drums or containers sustain damage in a vehicle accident that occurs during their transportation on CCAS or VAFB. The damage would be caused by the impact forces of the accident, from the container being ejected out of the delivery vehicle cargo bed and impacting the pavement or other rigid object, or from a combination of these two outcomes.

(3) The damage caused by an on-base vehicle accident involving KSC 2,500 mobile trailers is not expected to result in a propellant release. These trailers are specially designed for impact and penetration resistance at highway speeds. Accidents on CCAS or VAFB approximating these conditions are judged to be extremely improbable.

(4) The safety awareness of personnel involved in propellant transportation convoy operations further decreases the probability and potential consequences of vehicle accident-generated releases involving all classes of containers.

b. Release Mechanisms

(1) A puncture or break in portable hypergolic propellant container or tank is assumed to result from damage sustained in a transportation vehicle accident. Examples include a break in a 55-gallon drum weld, a penetration or separation of a 30- and 5-gallon drain container wall, or a broken/leaking connection stub or valve stem on a KSC drain container.

(2) Two release rates are assumed for 55-gallon drums:

- 0.1 gpm for a minor weld crack.
- 1.0 gpm for a major weld break or container wall puncture.

(3) The estimated propellant release rate for a damaged KSC drain container is 0.1 gpm. This low rate accounts for its crash protection and impact-resistant design features.

c. Amount of Propellant Released

(1) If no fire results from the accident conditions, release quantities are estimated by multiplying the appropriate gpm release rate by 70 minutes.

(2) If fire results, release quantities are estimated by multiplying the appropriate gpm release rate by 80 minutes.

(3) The 70 and 80 minute time periods represent estimates of fire department notification and response lead times, as defined in Table IX-2.

(4) If the product of the gpm rate times the fire department response time exceeds the capacity of the damaged container, then it is assumed that the release quantity was the full capacity of the container.

(5) Release amounts are summarized in Table IX-3.

Table IX-2. Estimated Fire Department Response Times For Propellant Container Vehicle Accidents (Vehicle Fuel Not Involved).

Emergency Response Task	Duration No-Fire	Duration Fire
Notification & arrival on-site.	5 min	5 min
Initial upwind, stand-off fire suppression operations (P-19 roof turret).	N/A	5 min
Establish perimeter security, upwind command post & entry control point.	15 min	15 min
Initial entry team dons Level A HAZMAT ensemble. Decon team establishes decon station	30 min	30 min
Entry team secures accident area with P-19 hand line, identifies leak source and installs temporary patch or plug to secure the leak	20 min	25 min
Total Elapsed Response Time To Plug Hypergolic Propellant Container Leak	**70 min**	**80 min**

Table IX-3. Propellant Container Releases used by Vehicle Accident Damage.

Fire Department Response Requirement	Minor Release	Major Release
No Fire	7-gal	55-gal*
Fire	8-gal	55-gal*

* - Assumed container leak rate drains contents prior to fire department initial entry response. From Table IX-2, 70 min X 1.0 gpm > 55-gal capacity.

d. Consequences of the Release

(1) Vehicle accidents that result in leaking hydrazine containers are assumed to generate a propellant fire situation.

(a) The fuel spill or vapors are assumed to contact rust (a metal oxide) on the vehicles, or

hot metal exhaust or motor surfaces, and to ignite. Fuel also may contact dry vegetation at the accident site or be absorbed by dust and/or fine-grained debris on the ground. This would support spontaneously ignition.

(b) It is assumed that the release rate will sustain the fire until the leak is plugged by the fire department's HAZMAT team, until the container is drained empty, or until the container position and leak location can no longer support gravity flow of the fluid.

(2) It is assumed that vehicle accidents that result in leaking oxidizer containers do not generate a propellant fire situation.

(3) Damaged vehicle fuel tanks may lead to combined fires involving leaking propellant containers and leaking vehicle fuel tanks.

(a) The vehicle fire can be caused either by initiation of the hydrocarbon fuel (MOGAS or diesel) or by hydrazine ignition.

(b) Leaking oxidizer will enrich a hydrocarbon fuel fire and cause it to burn with more intensity and at a higher temperature.

(c) Combined vehicle fuel - propellant fires would lead to larger fire areas and increased fire suppression response times. The potential for collateral fires involving nearby facilities or vegetation also would be increased. Significantly more agent quantities will be required to prevent the explosion of the vehicle fuel tank and/or propellant container. HAZMAT team entry into the release area may be required to be conducted under a water spray blanket for fire safety.

(4) All water and foam agent dispensed at the accident site must be contained and treated as hazardous waste.

(5) Hydrazine fuel fires and oxidizer-enriched fires produce extremely toxic combustion by-products. Once the fire has been extinguished, residual propellant may continue to flow from the damaged container. Highly toxic vapors will be produced. A toxic hazard corridor must be estimated by the Base Disaster Response Force (DRF) and evacuation notices made to personnel in the downwind plume.

(6) If no fire results, the major threats for both fuel and oxidizer incidents are toxic vapor hazards. As above, a toxic hazard corridor would be estimated by the DRF, and the fire department HAZMAT

Response Team would conduct operations to identify and terminate the leak.

7. Loading/Unloading Accident Involving Dropped Hypergolic Propellant Containers

a. Situation

(1) 55-gallon drums and KSC 30- and 5-gallon drain containers are transported from CCAS and VAFB storage areas to launch pad or payload processing facility end-users by a Government contractor-operated flat bed or pickup truck. These vehicles are fitted with a stainless steel bed and tie down eyes for proper grounding. They also may be fitted with a hydraulic lift tailgate.

(2) Loading and unloading of 55-gallon drums and small drain containers to and from the beds of transport vehicles, normally, is accomplished using loading ramps, drum hand dollies, or by tailgate lifts. CCAS loads 55-gallon drums using a fork lift fitted with a special drum-lifting attachment.

(3) 200-gallon cylinders and KSC 500 gallon GPTUs are normally loaded/off-loaded by fork lift. KSC GPTUs are transported on special, impact-resistant, stainless steel safety trailers.

(4) This scenario assumes that a container is dropped to a pavement surface during a lifting operation and damaged. A propellant release is assumed to result.

b. Release Mechanisms

(1) A puncture or break in portable hypergolic propellant container or tank is assumed to result from damage sustained in a transportation vehicle accident. Examples include a break in a 55-gallon drum weld, a penetration or separation of a 30- and 5-gallon drain container wall, or a broken/leaking connection stub or valve stem on a KSC drain container.

(2) Minor container damage is assumed to result from this accident scenario. The assumed release rate is 0.1 gpm. This low rate is based on an expected maximum container free-fall of four feet, and the impact-resistant design features of the KSC-designed containers. The safety awareness of personnel involved in propellant container lifting operations reduces accident probabilities to a very low level.

c. Amount of Propellant Released

The amount of propellant released as a result of a dropped container accident with minor damage is dependent on fire department response times, as defined in Table IX-2. The leak or release rate is assumed to be 0.1 gpm.

(1) If no fire results from the accident conditions, release quantities are estimated by multiplying 0.1 gpm release rate by 70 minutes, or 7-gallons.

(2) If fire results, release quantities are estimated by multiplying 0.1 gpm by 80 minutes, or 8-gallons.

d. Consequences of the Release

(1) A fire condition is assumed to result from an outdoor release of AH, MMH or A-50 involving a damaged container. Exterior fuel spills are assumed to contact a metal oxide or dry vegetation source or to be absorbed by dust and/or fine-grained debris on the ground, and to spontaneously ignite. It is assumed that the leak rate of 0.1 gpm would sustain the fire until the arrival of the fire department.

(2) Upon arrival of the fire department, the fire must be extinguished from an upwind, standoff position, and, then, the drum or tank would be cooled by water application. A P-19 crash/fire rescue vehicle, would be effective for these operations. Additional water application will be required to dilute the fuel and prevent re-ignition during the mobilization time for the HAZMAT Response Team.

(3) Hydrazine fuel fires produce extremely toxic combustion by-products. Once the fire has been extinguished, residual propellant may continue to flow from the damaged container. Highly toxic vapors will be produced. A toxic hazard corridor must be estimated by the Base Disaster Response Force (DRF) and evacuation notices made to personnel in the downwind plume.

(4) HAZMAT team entry to locate and plug the container leak would be conducted under a water spray blanket for fire safety.

(5) If no fire results, the major threats for both fuel and oxidizer incidents are toxic vapor hazards. As above, a toxic hazard corridor would be estimated by the DRF, and the fire department HAZMAT Response Team would conduct operations to identify and terminate the leak.

8. Vehicle Accident Involving Hypergolic Propellant Sample Containers

a. Situation

(1) Glass and stainless steel sample containers are filled at fuel storage locations or payload processing facilities and transported to an on-base laboratory for analysis. The purpose of the analysis is to ensure that propellants distributed to end-users meet specified program requirements for chemical content and purity. Four glass sample bottles are placed in a single, sealed, stainless steel carrying container. One or more Hoke bottles are placed in a cradle for transportation to the laboratory.

(2) This scenario assumes that a vehicle accident occurs during the on-base transportation of filled sample containers to the analysis laboratory. Damage to the container vessels would result in the release of fuel or oxidizer.

b. Release Mechanisms

(1) Fuels

A transportation container with four, 1-liter glass sample bottles is assumed to be involved in the vehicle accident. All four glass bottles are assumed to be broken and the carrying container is assumed to have been broken open upon impact. The propellants are assumed to be released at the accident site.

(2) Oxidizer

One Hoke bottle is assumed to have sustained sufficient damage upon impact to result in the release of its contents (1-liter).

c. Amount of Propellant Released

(1) The maximum estimated propellant fuel release is, approximately, 1-gallon of hypergolic fuel from four broken, 1-liter, glass sample flasks.

(2) The estimated oxidizer release quantity is the capacity of one stainless steel Hoke bottle or, approximately, 0.25-gallons.

d. Consequences of the Release

(1) Fire and toxic vapor hazards are assumed to result from a vehicle accident involving broken or leaking fuel containers. The release quantity is 1-gallon

or less and some of the propellant may evaporate before ignition occurs. Therefore, a fire would rapidly consume the released propellant. Both the burn and evaporation durations depend, primarily, on the surface area size and depth of the accident spill pool, and on wind and humidity conditions.

(2) It is assumed a vehicle accident that results in a leaking oxidizer Hoke container does not involve a propellant fire situation.

(3) Toxic vapor hazards from combustion products and spilled liquid propellants would be a major threat to personnel in the immediate area of the accident. This would include the driver of the propellant transport vehicle, other drivers involved.

(4) Concerned personnel at the crash site will want to render assistance. They may not be aware of the toxic cargo involved in the accident and that a release has taken place. DOT hazardous material placards are required on containers and vehicles, however, by-standers may not detect the presence of placards or a leaking sample container before inhalation occurs.

(5) Upon arrival of the fire department, the fire must be extinguished from an upwind, standoff position. A P-19 crash/fire rescue vehicle, would be effective for these operations.

(6) If the accident results in injuries to vehicle occupants, the fire department must make a very rapid determination of the location of damaged containers and the associated toxic vapor concentrations. Since release quantities are small, an upwind approach that is conducted under a water spray blanket for vapor suppression may be feasible. Fire fighters must be protected by self-contained breathing apparatus (SCBA) for such an operation.

9. Transportation or Mating Accident Involving a Fueled Satellite Payload

a. Situation

(1) Satellites may be processed in ground-level clean room facilities and then transported to the launch pad for mating to the launch vehicle. The satellite is placed in a special transportation shroud to seal out contaminants and loaded on a truck or trailer bed. Special transportation convoy procedures are followed to safeguard payloads. They include security police escort vehicles, very slow speeds, and movement timing to avoid periods of high traffic density. The payloads are off-loaded at the

launch site and lifted by crane for mating to the upper stage vehicle.

(2) Some payloads for NASA-KSC or CCAS missions are processed at an off-base facility located in Titusville, Florida. This requires the movement of the fueled payload over public access roads. Convoy procedures are as defined above.

(3) This scenario assumes a satellite lifting or transportation accident that damages the charged fuel system and results in a propellant leak condition.

b. Release Mechanisms

(1) Vehicle and lifting accidents involving fueled payloads are assumed to result in a severe dynamic impact to the shroud-payload system. It is assumed that the shock is transmitted to the payload propellant subsystem, and that a break or material failure takes place that results in propellant release. Expected failure points include weld or pipe connections associated with propellant storage tanks or distribution lines.

(2) The loss of integrity of the fuel subsystem would result in a pressurized propellant release. The propellant may be contained within the satellite transportation shroud or it could be released to the open air in a clean room or at an outdoor accident site.

(3) A release rate of 0.1 gpm is assumed. This low estimate accounts for the protective packaging of the payload, the convoy safety precautions, and the safety operations involved in satellite lifting and mating.

c. Amount of Propellant Released

(1) The amount of propellant released as a result of a fueled payload accident with minor damage is dependent on the notification and arrival and of the payload fuel subsystem technician, and his/her donning of the SCAPE ensemble and entry into the propellant release zone. The leak or release rate is assumed to be 0.1 gpm.

(2) Release quantities are estimated by multiplying the 0.1 gpm release rate by the technician response times indicated at Table VIII-4.

(3) Release quantities are summarized, as follows:

- Duty hours/on-base: 9-gallons.
- Duty hours/off base: 10.5-gallons.
- After duty hours/on-base: 12-gallons.
- After duty hours/off-base: 13.5-gallons.

d. Consequences of the Release

(1) A fire condition is assumed to result from a pressurized release of AH, MMH or A-50. Spontaneous ignition is assumed from the heat of friction of the pressurized release and the fine spray that is produced. It is assumed that the pressurized leak rate of 0.1 gpm would sustain the fire until the arrival of the fire department.

(2) Upon arrival of the fire department, the fire must be extinguished from an upwind, standoff position. A water spray hand line operation is suggested.

(3) Extinguishment may be difficult or impossible to accomplish, because:

- Access to the fire and leak source may be blocked by the payload shroud or other external covers/panels.
- Pressurized fuel fires are difficult to extinguish under any circumstances.

(4) If access to the fire is not available, the fire department must continue to apply water to the payload container to minimize the potential for a fuel system explosion, and await the arrival of knowlegeable payload technicians to plan further actions.

(5) Hydrazine fuel fires produce extremely toxic combustion by-products. Once the fire has been extinguished, residual propellant may continue to flow from the damaged payload. Highly toxic vapors will be produced. A toxic hazard corridor must be estimated by the Base Disaster Response Force (DRF) and evacuation notices made to personnel in the downwind plume.

(6) Payload technician entry to locate and plug the fuel subsystem leak would be supported by a fire department HAZMAT backup team. Fire fighters should establish a water spray blanket for explosion prevention and fire safety.

Table IX-4. Estimated Fire Department Response Times For Fueled Payload Vehicle Accidents Or Accidents During Payload - Booster Mating.

Emergency Response Task	**Duration Duty Hrs**	**Duration After Duty Hrs**
Fire department notification & arrival on-site.	5 min/ 15 min*	5 min/ 15 min*
NASA KSC or VAFB life support contractor notification & arrival on-site with SCAPE protective ensembles.	15 min/ 30 min*	60 min/ 75 min*
Payload fuel systems technician notification & arrival on-site.**	30 min/ 45 min*	60 min/ 75 min*
Establish perimeter security, upwind command post & entry control point.	15 min	15 min
Initial fire department upwind, stand-off fire suppression operations (Pumper water spray hand line).	5 min	5 min
Fire department HAZMAT initial entry team dons Level A HAZMAT ensemble and stands by for fire re-ignition or other emergency. Decon team establishes decon station. HAZMAT team awaits arrival of payload technicians & life support personnel.	30 min	30 min
Payload technicians don SCAPE ensembles, enter hazard area, identify leak source and install temporary patch or plug to secure the leak.**	60 min	60 min
Entry team secures payload fuel subsystem with water spray hand line and supports payload technicians as emergency backup team.	20 min	20 min
Total Elapsed Response Time To Plug Hypergolic Propellant Container Leak. (Note: All Times are not additive)	**90 min/ 105 min***	**120 min 135 min***

Notes: * - Indicates an off-base accident response time.
** - Indicates timeline critical path activities that are included in total elapsed time estimate.

(7) If no fire results, the major threats for both fuel and oxidizer incidents are toxic vapor hazards. As above, a toxic hazard corridor would be estimated by the DRF, and the fire department-payload technician joint response team would conduct operations to safe the accident site, and identify and terminate the leak.

(8) Because of the ultra-high value of payloads, extremely detailed pre-planning between the fire department and payload managers is required to ensure that any fire suppression response involving satellites is conducted with minimum system damage. However, payload value must be balanced with the DRF's responsibility at the accident site to minimize personnel exposures to toxic chemical releases and to prevent fire-induced explosions at both on- and off-base accident sites.

F. USE OF HAZARD ANALYSIS DATA FOR PRE-FIRE PLANNING

1. Pre-Fire Plans are prepared for each facility on base. They identify the floor plan and site layout, hazards contained in the facility, locations of fire protection systems, hydrants and hose standpipes. They also contain notes on special tactics, agents and other operational considerations for fire suppression and rescue.

2. Figure IX-5 shows a suggested process to apply hazard analysis results to fire department pre-fire planning documents. The threat example is a propellant transfer operation inside a MST clean room. A Centaur Reaction Control System hydrazine fueling is depicted. Relevant fire department planning factors are as follows:

a. The expected accidental release is assumed to be caused by an improper flexible hose connection or a transfer system material failure. The estimated release is 1.0-gallons. Smaller releases in the “drip and drop” category are assumed to be “incidental”.

b. Release signatures would be colorless hydrazine vapors. Personnel inside the clean room during transfer operations are attired in SCAPE ensembles, therefore the characteristic hydrazine "fishy" odor would not be detected. Vapor detection would be accomplished by hand-held detectors and/or installed hydrazine vapor detection systems. A hydrazine flame detection system would significantly improve accident recognition and response times, should this threat occur. This capability is not available off-the-shelf at this time.

c. Because of the clean room environment and the availability of aspirators and emergency exhaust systems for spill control, it is assumed that small hydrazine releases will not result in vapor ignition.

d. Fire fighters and clean room occupants should be trained on hydrazine fire recognition. Combustion signatures are very difficult to detect. Hydrazine flames are colorless and produce no visible smoke. They burn at about 2,100 $^{\circ}$F, or some 300 degrees hotter than hydrocarbon fuel fires. Visible flame and smoke may be produced by the

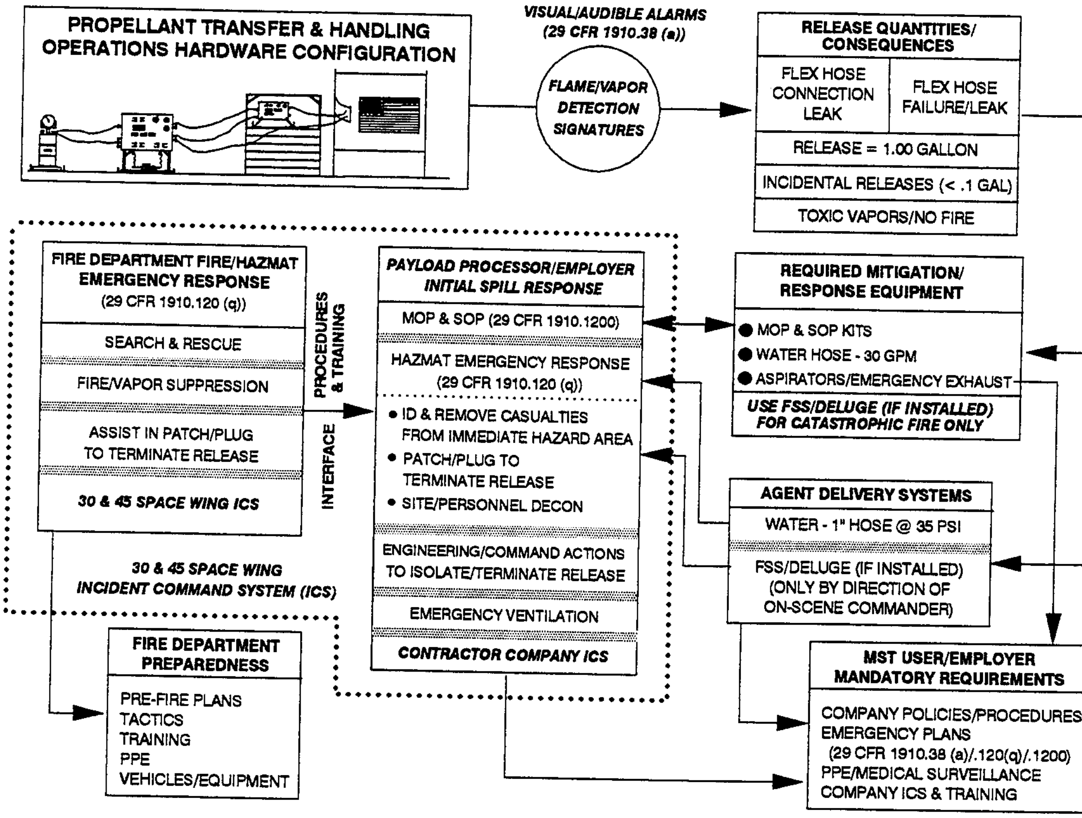


Figure IX-5. Use of Hazard Analysis Data For Fire Department Pre-Fire Planning.

collateral combustion of other materials involved in the fire.

e. Fire fighters are not inside the clean room during propellant transfer operations. Therefore, the immediate emergency response to a clean room propellant release must be conducted by the personnel involved in the hazardous operation.

(1) Small releases can be rapidly neutralized and cleaned up by mop and sop operations and aspirators. Emergency ventilation systems can be activated to keep clean room vapor concentration levels well below the Lower Explosive Limit (LEL) for hydrazine or MMH.

(2) Water for fuel spill dilution or fire suppression should be available in each clean room. A 1-inch garden hose is sufficient for this purpose.

f. The primary fire fighter mission in response to clean room propellant spills or small fires would be to assist in the rescue and egress of injured occupants. To enter a contaminated clean room, fire fighters must be donned in OSHA 29 CFR 1910.120(q) Level A, fully-encapsulated HAZMAT ensembles.

3. Once Pre-Fire Plans are completed for specific facilities and operations involving hypergolic propellants, operational response data should be extracted and consolidated into training programs. This information also can be used to identify and justify increases in protective equipment, agent inventories and/or vehicles.

G. CCAS TOXIC HAZARD CORRIDOR EXAMPLE

1. Toxic Hazard Corridor (THC) lengths for hydrazine and nitrogen tetroxide spills on were computed for a "typical" CCAS daytime weather pattern. Results are presented at Figure IX-6. The Air Force Geophysics Laboratory's Ocean Breeze-Dry Gulch equation was used:

$$THC = SN \bullet \left| \frac{CP}{Q} \right|^{-.51} \bullet (DT + 10)^{2.209} \bullet SD^{-.258} \qquad (1)$$

where:

THC = Downwind toxic corridor length (ft).
SN = Constant based on the gram molecular weight of the propellant compound.
CP = Peak concentration of the hypergolic propellant spilled/released (ppm).
Q = Source strength/evaporation rate of the spilled propellant (lbs per minute per square foot).
DT = The temperature at 54 ft above the ground surface minus the temperature at 6 ft (^{o}F).
SD = Standard deviation of the wind direction (^{o}).

2. Assumed Ocean Breeze-Dry Gulch Equation Parameters

a. For nitrogen tetroxide and monomethyl hydrazine (MMH), SN is assumed to be 12.87. For hydrazine and A-50, SN is assumed to be 15.48.

b. CP is assumed to be the Short Term (30-Minute) Public Emergency Guidance Level established by the National Research Council's Committee on Toxicology. For hydrazine and A-50, CP is 0.24 ppm and for MMH, CP is 0.48 ppm. CP for nitrogen tetroxide is 2.00 ppm.

CCAS TOXIC CORRIDOR LENGTH (OCEAN BREEZE/DRY GULCH EQUATION) $THC = SN \bullet \left\| \frac{CP}{Q} \right\|^{.51} \bullet (DT + 10)^{2.209} \bullet SD^{-.258}$ RELEASE SCENARIO/(QUANTITY)	RELEASE & TOXIC PLUME GENERATION PARAMETERS							
	SPILL SIZE (SQ FEET)	SPILL POND DIAMETER (FT)	TOXIC CORRIDOR LENGTH (FT)	CP = PPM = HAZMAT CONCENTRATION	Q = HAZMAT EVAPORATION RATE (LB/MIN)	DT = T54' - T6'	SD = WIND DEG STD DEVIATION	SN = CONSTANT
NITROGEN TETROXIDE (N2O4)	***0.1 INCH THICK SPILL POND EVAPORATES IN 5.2 MINUTES (ALL SIZES)***							
● DRUM/CONTAINER TRANSFER & CLEAN ROOM PAYLOAD/CENTAUR FUELING (1 GAL)	16	4.5	559	2.00	1.6	-2	10	12.87
● SMALL DRUM/CONTAINER PUNCTURE (8-GAL)	128	12.8	1,811	2.00	12.8	-2	10	12.87
● SEVERE DRUM/CONTAINER PUNCTURE (55 GAL)	882	33.5	4,320	2.00	88.2	-2	10	12.87
● PAYLOAD ACCIDENT/LEAK (13.5-GAL)	216	16.6	2,363	2.00	21.6	-2	10	12.87
● DELTA STAGE II FUELING (40 GAL)	642	28.6	3,671	2.00	64	-2	10	12.87
● VENDOR-BASE TANKER TRANSFER (100 GAL)	1,604	45.2	5,854	2.00	160	-2	10	12.87
● TITAN RSV FILL (200 GAL)	3,208	63.9	8,349	2.00	321	-2	10	12.87
● TITAN STAGE II FILL (200 GAL)	3,208	63.9	8,349	2.00	321	-2	10	12.87
● TITAN TVC FUEL/DEFUEL (240 GAL)	3,850	70.0	9,160	2.00	385	-2	10	12.87
● TITAN STAGE I FUEL/DEFUEL (400 GAL)	6,417	90.4	11,889	2.00	642	-2	10	12.87
AEROZINE-50 (A-50)	***0.1 INCH THICK SPILL POND EVAPORATES IN 26.1 MINUTES (ALL SIZES)***							
● DELTA STAGE II FUELING (40 GAL)	642	28.6	6,416	0.24	12.8	-2	10	15.48
● VENDOR-BASE TANKER TRANSFER (100 GAL)	1,604	45.2	10,237	0.24	32	-2	10	15.48
● TITAN RSV FILL (200 GAL)	3,208	63.9	14,602	0.24	64.2	-2	10	15.48
● TITAN STAGE II FILL (200 GAL)	3,850	70.0	14,602	0.24	64.2	-2	10	15.48
● TITAN STAGE I FUEL/DEFUEL (400 GAL)	6,417	90.4	20,785	0.24	128.3	-2	10	15.48
ANHYDROUS HYDRAZINE (N2H4)	***0.1 INCH THICK SPILL POND EVAPORATES IN 26.1 MINUTES (ALL SIZES)***							
● DRUM/CONTAINER TRANSFER & CLEAN ROOM PAYLOAD/CENTAUR FUELING (1 GAL)	16	4.5	978	0.24	0.32	-2	10	15.48
● SMALL DRUM/CONTAINER PUNCTURE (8-GAL)	128	12.8	2,366	0.24	2.6	-2	10	15.48
● SEVERE DRUM/CONTAINER PUNCTURE (55 GAL)	882	33.5	7,547	0.24	17.6	-2	10	15.48
● PAYLOAD ACCIDENT/LEAK (13.5-GAL)	216	16.6	3,058	0.24	4.3	-2	10	15.48
MONOMETHYL HYDRAZINE (MMH)	***0.1 INCH THICK SPILL POND EVAPORATES IN 26.1 MINUTES (ALL SIZES)***							
● DRUM/CONTAINER TRANSFER & CLEAN ROOM PAYLOAD/CENTAUR FUELING (1 GAL)	16	4.5	509	0.48	0.32	-2	10	12.87
● SMALL DRUM/CONTAINER PUNCTURE (8-GAL)	128	12.8	1,662	0.48	2.6	-2	10	12.87
● SEVERE DRUM/CONTAINER PUNCTURE (55 GAL)	882	33.5	3,932	0.48	17.6	-2	10	12.87
● PAYLOAD ACCIDENT/LEAK (13.5-GAL)	216	16.6	2,147	0.48	4.3	-2	10	12.87

Figure IX-6. CCAS Toxic Hazard Corridors (Ocean Breeze-Dry Gulch Equation).

c. The spill hazardous chemical source strength parameter, Q, is 0.1 lbs/min/sq foot for nitrogen tetroxide and .02 lbs/min/sq foot for hydrazine, MMH and A-50.

d. The temperature difference, TD, between 54 and 6-foot levels at CCAS during a daylight release was assumed to be minus 2 degrees.

e. The wind direction standard deviation, SD, was assumed at 10 degrees.

f. All parameters for THC calculations were taken from "*Hypergolic Propellant Hazard Response Guide, Cape Canaveral Air Force Station*", Volume IV, Appendices, ICF Technology Incorporated, Fairfax, VA, December 1988 (Unpublished).

3. The primary factor that determines the toxic corridor length is the size of the spill area.

a. The larger the spill surface area, the more hypergolic propellant is off-gassed to the atmosphere to produce hazardous peak concentrations of vapors.

b. In general, hydrazine-based fuel spills produce THCs about twice as long as those produced by oxidizer spills. This is because the permissible peak concentration for hydrazine and A-50 is eight times lower than that for nitrogen tetroxide.

c. Hydrazine fuels take about 26 minutes to evaporate, assuming a 0.1 inch pond depth. N_2O_4 spills of equal size and depth require only about 5 minutes to evaporate. Therefore, an unattended hydrazine spills will continue to produce downwind toxic vapor hazards for a much longer time period than will nitrogen tetroxide.

4. It is emphasized that the THC calculations for CCAS are first-order approximations. The Ocean Breeze-Dry Gulch equation used does not account for the lateral and vertical mixing of HAZMAT chemicals or the three-dimensional variations in temperature and wind direction parameters. Results are good working estimates for CCAS Fire Department emergency planning purposes. Real-time THC calculations for accidental releases at actual sites are provided by on-line CCAS and VAFB range meteorological computer system data available to the DRF incident command structure.

SECTION X

PROPELLANT TRANSFER ACCIDENT RELEASE QUANTITIES

A. ACCIDENTAL RELEASE MECHANISM SUMMARY

The hazard analysis described in Section IX identified four distinct hypergolic propellant accidental release mechanisms involving transfer system components. These mechanisms determined the quantity of hypergolic chemical released. They are:

1. The improper seating of stainless steel hose disconnect hardware with additional hose lengths and/or the fixed connection points of the mobile tanker or bulk storage facility.

   a. A small leak under transfer pressure results. The problem is identified and the dynamic transfer is terminated. The leak point is isolated and/or the affected hose length is purged.

   b. The assumed release is the volume of product transferred by the propellant transfer unit (PTU) at its normal operating flow rate (gpm) before the leak location can be identified and flow can be terminated. The time to identify and isolate the leak point is estimated at 2 minutes.

   c. The release quantity is dependent on the operating flow rate of the PTU.

2. Leaks through a breach in a stainless steel hose section or in a fixed distribution system component. These can be caused by temperature, fatigue or reactive chemical - induced deterioration and subsequent material failure under transfer pressures.

   a. A leak under transfer pressure results. The problem is identified and the dynamic transfer is terminated. The leak point is isolated and/or the affected piping is purged.

   b. The assumed release is the volume of product transferred by the propellant transfer unit (PTU) at its normal operating flow rate (gpm) before the leak location can be identified and flow can be terminated. The time to identify and isolate the leak point is estimated at 2 minutes.

   c. The release quantity is dependent on the operating flow rate of the PTU.

3. Deterioration, temperature-induced displacements, material fatigue, cathodic erosion, and/or improper maintenance of a propellant transfer system component, such as a valve, flowmeter, pipe or connection fitting that results in a material failure or joint separation.

a. A leak under transfer pressure results. The problem is identified and the dynamic transfer is terminated. The leak point is isolated and/or the affected piping is purged.

b. The assumed release is the volume of product transferred by the propellant transfer unit (PTU) at its normal operating flow rate (gpm) before the leak location can be identified and flow can be terminated. The time to identify and isolate the leak point is estimated at 2 minutes.

c. The release quantity is dependent on the operating flow rate of the PTU.

4. Human Factors.

a. Failure to comply with official procedures could result in the routing and transfer of propellants to a non-authorized destination. Examples include vent pipes or open sump areas.

b. The assumed release is the volume of product transferred by the propellant transfer unit (PTU) at its normal operating flow rate (gpm) before the leak location can be identified and flow can be terminated. The time to identify and isolate the leak point is estimated at 2 minutes.

c. The release quantity is dependent on the operating flow rate of the PTU.

B. ESTIMATED DYNAMIC TRANSFER ACCIDENTAL RELEASE QUANTITIES - CCAS FUEL STORAGE AREA #1

1. There are no fixed fuel or oxidizer storage facilities at CCAS that are in use at the present time. Bulk storage for A-50 and oxidizer is provided by vendor and KSC 2,500-gallon tanker-trailers. These mobile units are parked on dispersed hardstands throughout FSA #1.

2. Figure X-1 identifies the three basic dynamic propellant (fuel and oxidizer) transfer operations that take place at FSA #1 involving propellant containers and tanker-trailer units. Each has the potential for an accidental release that could initiate a fire department emergency response. Figure X-2 shows the mobile propellant transfer unit (PTU) used for most transfer operations.

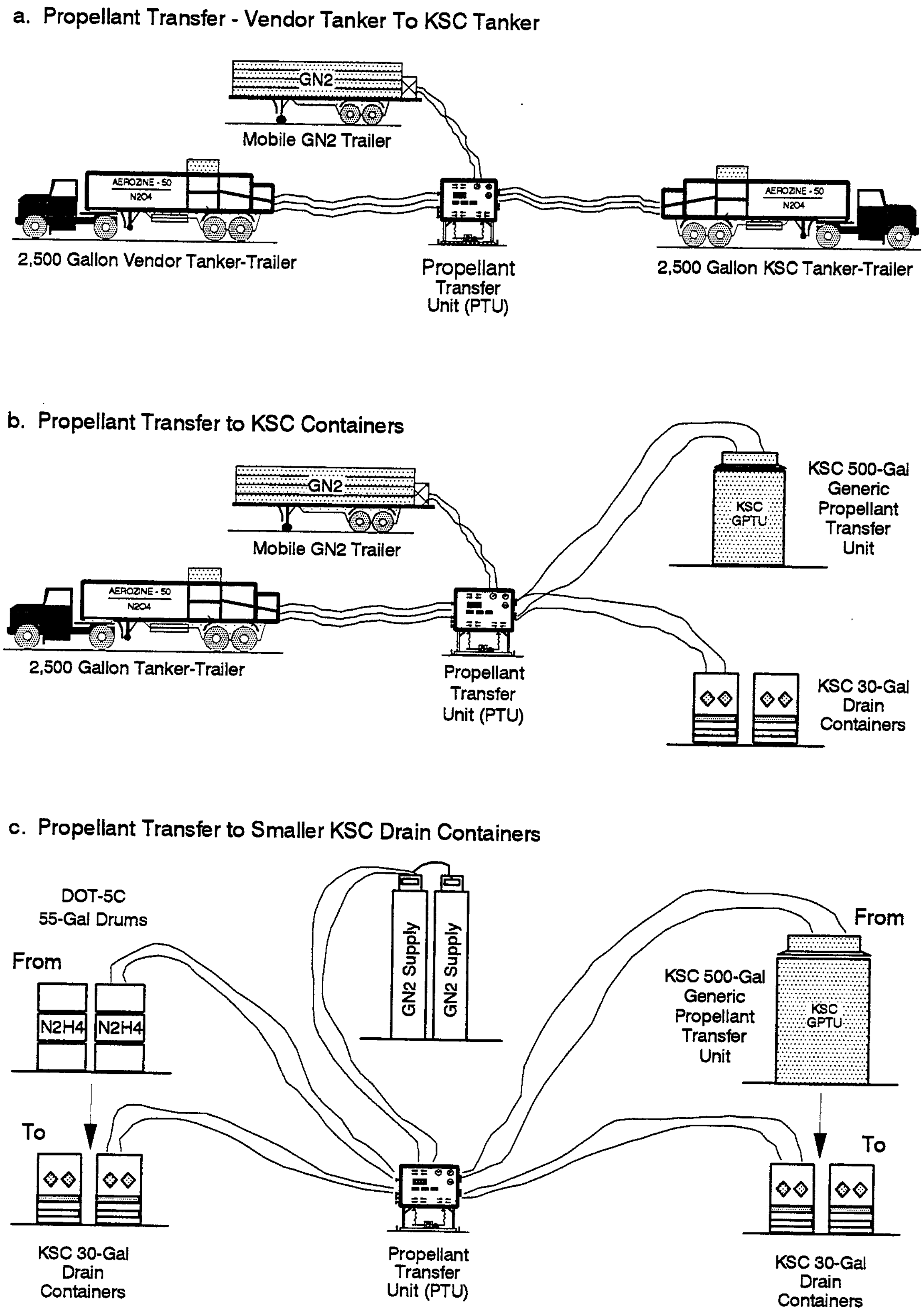


Figure X-1. Representative CCAS Fuel Storage Area #1 Propellant Transfer Operations.

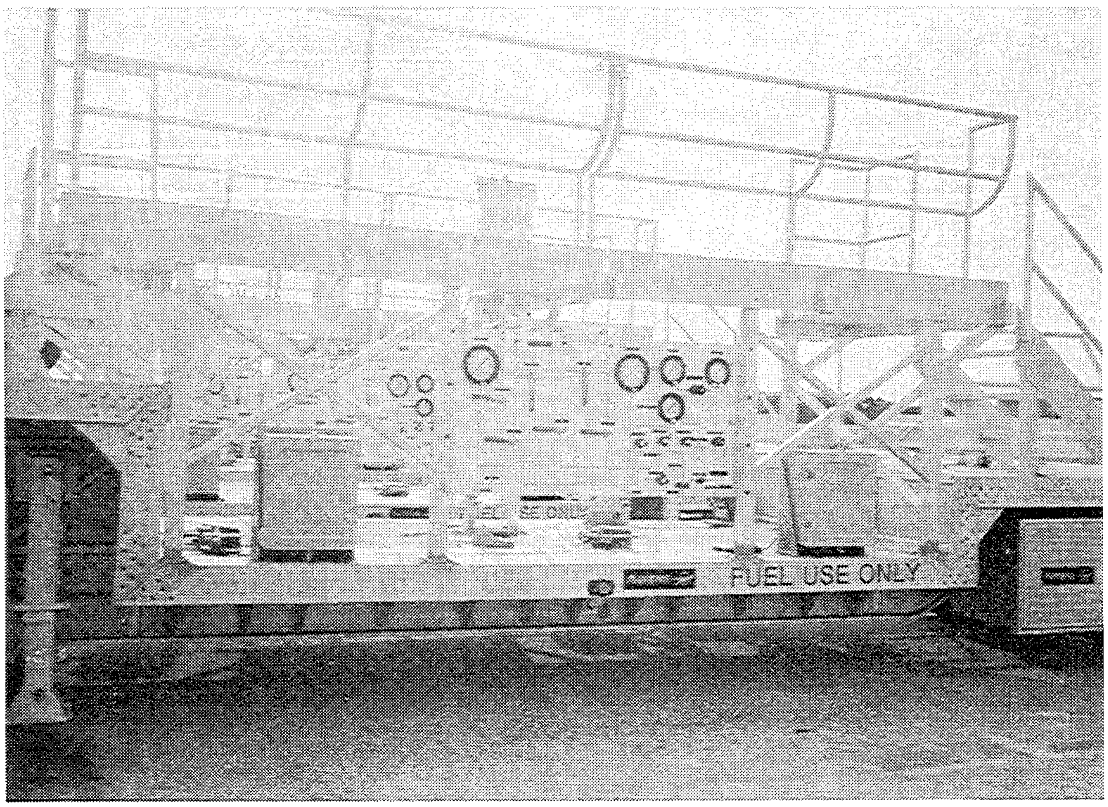


Figure X-2. KSC Mobile Propellant Transfer Unit (PTU).

a. 2,500-Gallon Vendor Trailers to KSC 2,500-Gallon Trailers

(1) Transfer operations between vendor and KSC-owned 2,500-gallon tankers are conducted using a portable propellant transfer unit (PTU) and a mobile 2,000 psi nitrogen trailer. Stainless steel flexible hoses are 10- and 15-feet in length and 1 1/4-inches in diameter. 20-foot lengths are typical.

(2) The PTU is normally operated at a 50 gpm peak flow rate. The credible leak release quantity is estimated at 100 gallons (2 minutes X 50 gpm).

b. 2,500 Gallon KSC Liquid Tanker Trailers to 500 Gallon GPTUs

(1) Transfer operations between KSC 2,500-gallon liquid tankers and 500-gallon GPTUs are conducted using a portable PTU and a mobile 2,000 psi nitrogen source.

Stainless steel flexible hoses are 1-inch in diameter. 10-, 15-, and 20-foot lengths are typical.

(2) The PTU is normally operated at a 25 to 50 gpm peak flow rate. The large leak credible release quantity is estimated at 100 gallons (2 minutes X 50 gpm).

c. 55-Gallon Drums to KSC 500-Gallon GPTUs and/or to 30- or 5-Gallon KSC Drain Containers

(1) Transfer operations between drums and KSC containers or between KSC containers and KSC containers are conducted using a portable PTU and a mobile nitrogen source. Stainless steel flexible hoses are 10 and 15 feet in length and 1/2 to 3/8 inches in diameter.

(2) The PTU is normally operated at a 1 - 5 gpm peak flow rate. The credible release quantity is estimated at 10 gallons (2 minutes X 5 gpm).

C. ESTIMATED DYNAMIC TRANSFER ACCIDENTAL RELEASE QUANTITIES - VAFB HYPERGOLIC STORAGE FACILITY (HSF)

1. The basic dynamic transfer operation that is conducted in the HSF involves the offload or loading of vendor and VAFB-owned 2,500-gallon trailers into or from fixed fuel and oxidizer bulk storage tanks (Figure X-3).

2. Tanker-trailers are connected to the fixed distribution manifold inlet system via 3-inch flexible stainless steel hose. Nominal hose lengths are 15- and 20-feet.

3. Transfer operations between vendor and VAFB-owned tankers and fixed bulk storage tanks are conducted using the fixed-pipe propellant transfer system. The transfer system is normally operated at a 150 gpm peak flow rate. The credible release quantity is estimated at 300 gallons (2 minutes X 100 gpm).

D. ESTIMATED DYNAMIC TRANSFER ACCIDENTAL RELEASE QUANTITIES - CCAS TITAN IV FUEL AND OXIDIZER STORAGE AREAS

1. Figure X-4 shows a generalized schematic of the propellant transfer configuration at CCAS Titan IV fuel and oxidizer holding areas.

2. Tanker trailers are connected to fixed inlet piping via 1 1/4-inch flexible stainless steel hose. The nominal hose length is 20-feet.

3. RSVs are filled from trailers at a peak flow rate of 100 gpm. The large leak credible release quantity is estimated at 200 gallons (2 minutes X 100 gpm).

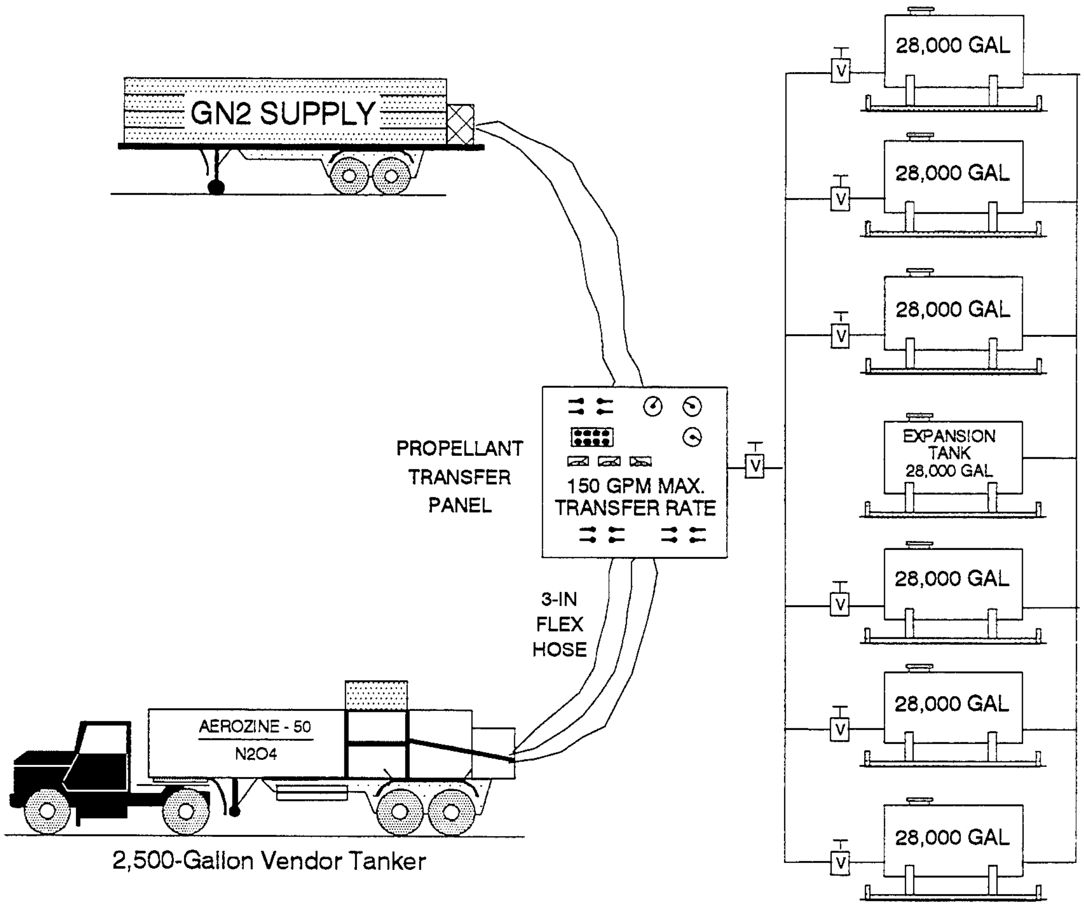


Figure X-3. VAFB HSF Propellant Transfer Schematic.

4. Railcar tank cars are connected to fixed inlet piping via 2-inch flexible stainless steel hose. The nominal hose length is 20-feet. RSVs are filled from rail cars at a peak flow rate of 100 gpm. The credible release quantity for a large leak is estimated at 200 gallons (2 minutes X 100 gpm).

E. ESTIMATED DYNAMIC TRANSFER ACCIDENTAL RELEASE QUANTITIES - VAFB TITAN IV FUEL AND OXIDIZER STORAGE AREAS

1. Figure X-5 shows a generalized schematic of the propellant transfer configuration at VAFB Titan IV fuel and oxidizer holding areas.

2. Tanker trailers are connected to fixed inlet piping via 3-inch flexible stainless steel hose. The nominal hose length is 20 feet.

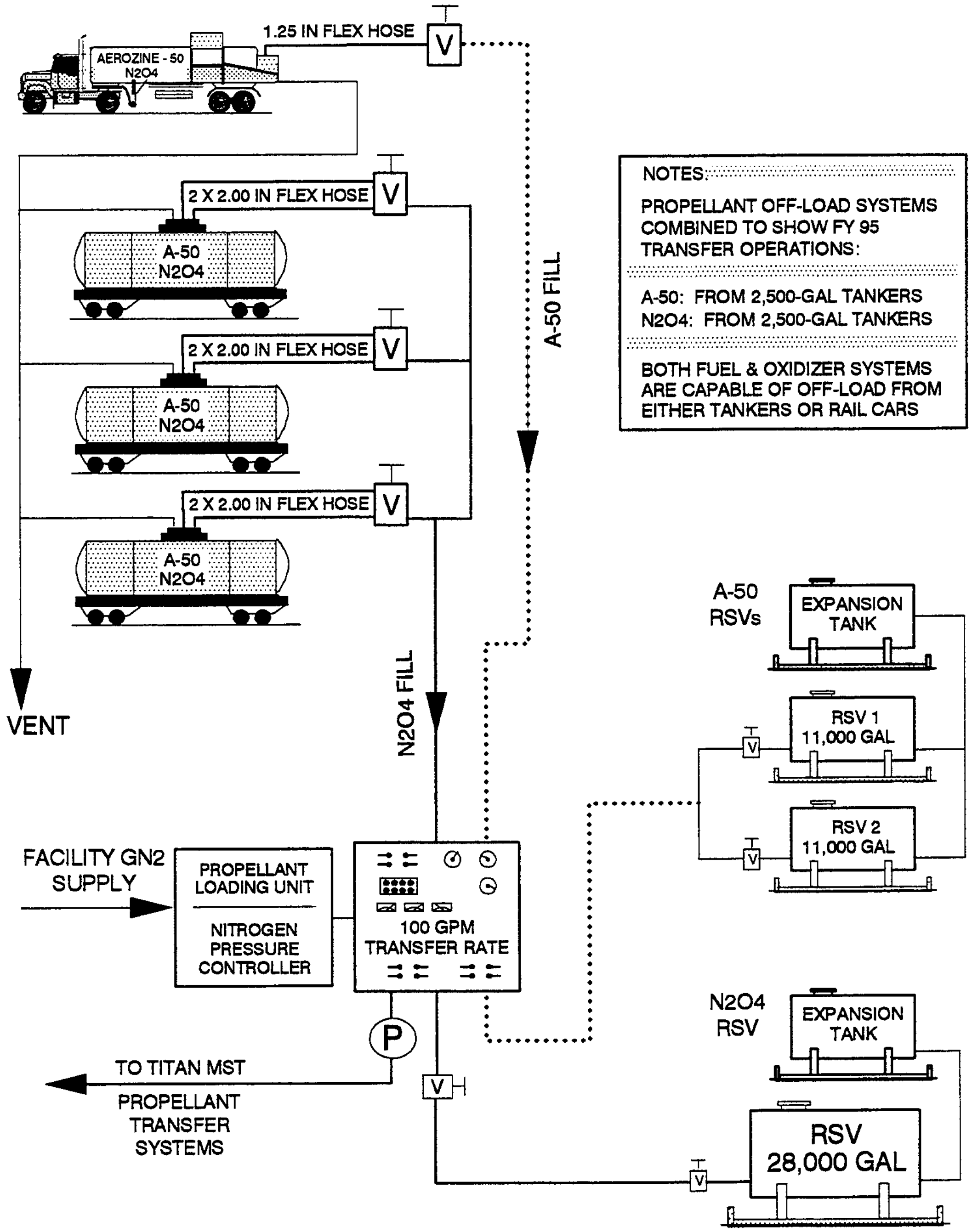


Figure X-4. CCAS Titan IV Fuel and Oxidizer Transfer Schematic.

3. RSVs are filled from trailers at a peak flow rate of 100 gpm. The large leak credible release quantity is estimated at 200 gallons (2 minutes X 100 gpm).

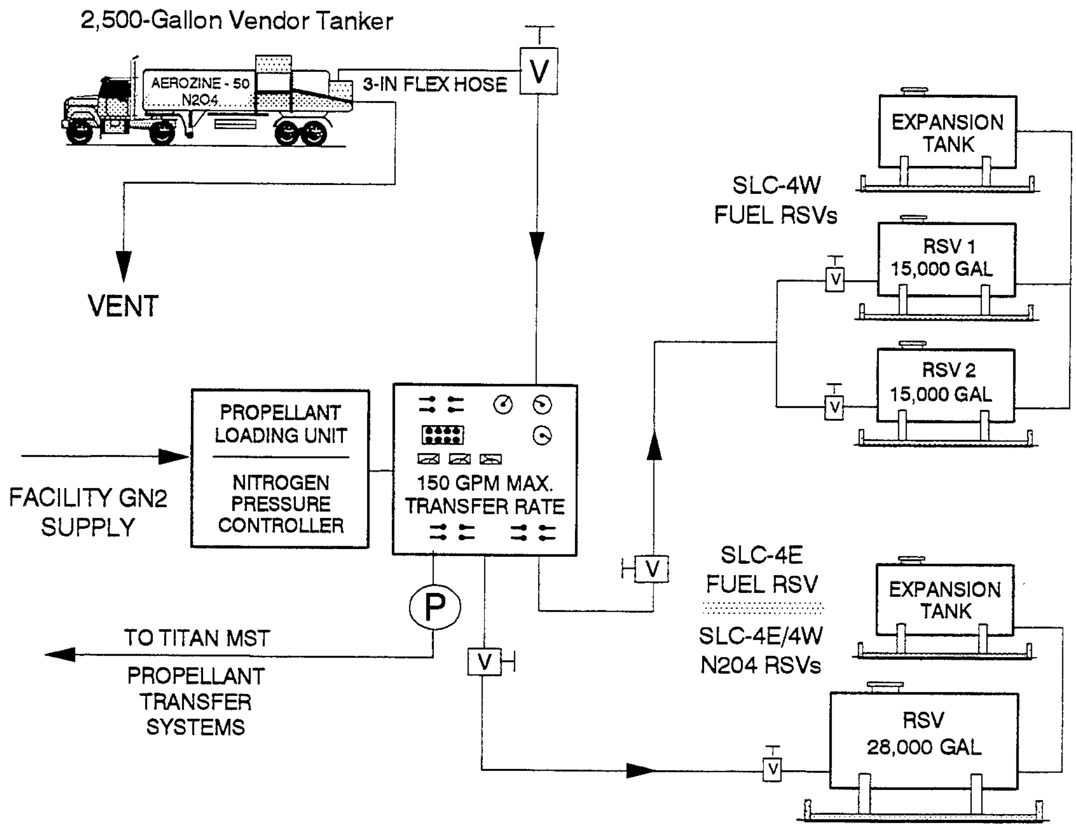


Figure X-5. VAFB Titan IV Fuel and Oxidizer Transfer Schematic.

F. ESTIMATED DYNAMIC TRANSFER ACCIDENTAL RELEASE QUANTITIES - CCAS AND VAFB CLEAN ROOM SATELLITE AND CENTAUR FUELING OPERATIONS

1. Figure X-6 depicts a generalized schematic for CCAS and VAFB operations involving propellant transfer from portable containers to a satellite or Centaur fuel system. Satellite fueling may take place either in ground-level clean room facilities or in Mobile Service Tower (MST) clean rooms after the payload has been mated to the launch vehicle. Titan and Delta Centaur Reaction Control System (RCS) fuel tanks are filled from MST clean rooms.

2. 55 gallon drums, KSC 30- and /or 5-gallon drain containers, or some program-specific fuel cart are prepositioned in the clean room. Fill, vent and drain lines are connected to a portable, vacuum pump-operated, service panel that also is set inside a drip pan. The fill line is routed to a fill and service panel (in a drip pan) for final flow control and/or sampling, and then to the payload fuel

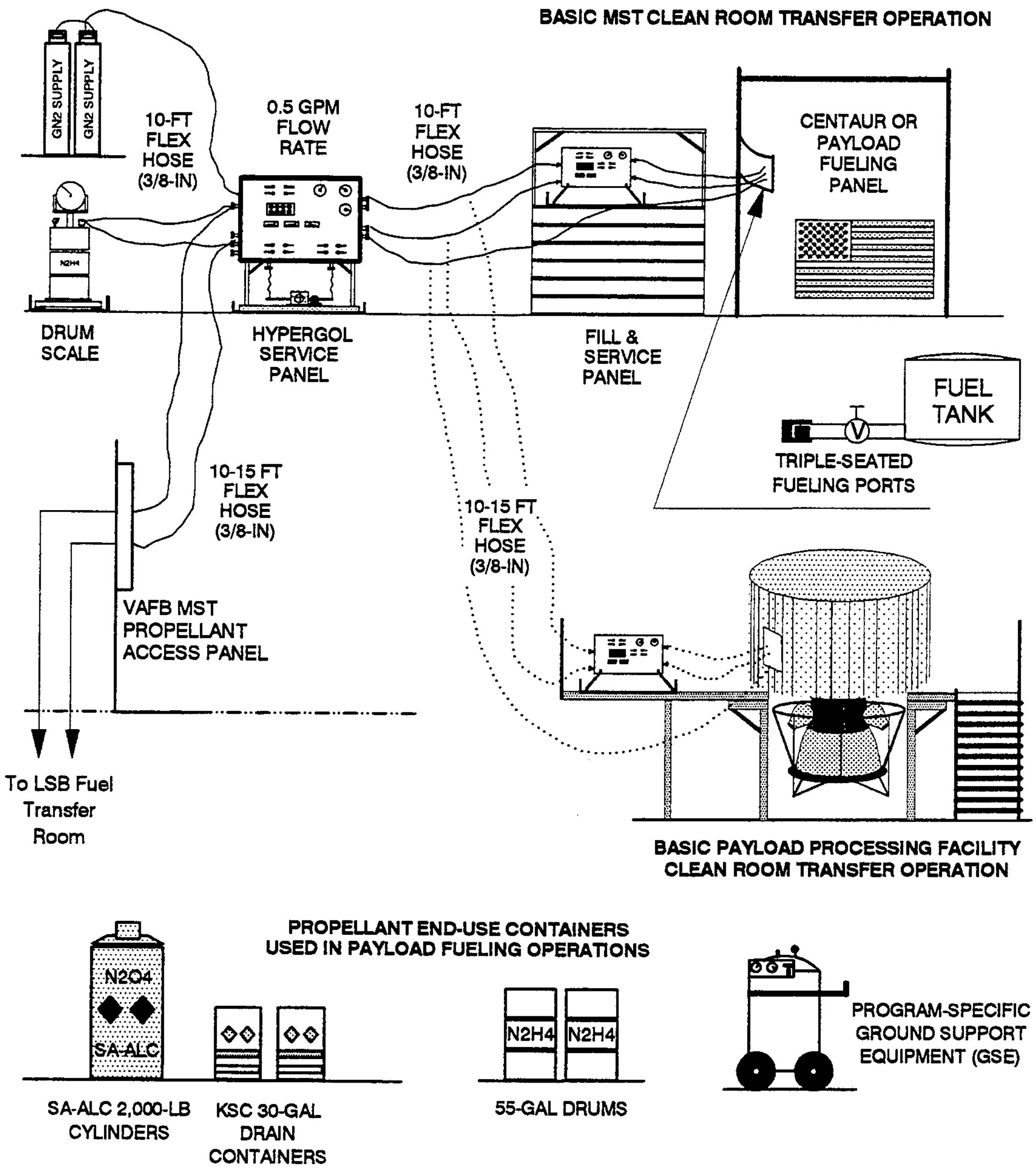


Figure X-6. Generalized Clean Room Satellite Fuel Transfer Schematic.

tank. Connections between all components are by stainless steel flexible hose sections.

3. Stainless steel flexible hose sections, typically, are 3/8-inches in diameter and 10- to 15- feet long.

4. Clean room propellant service panels are normally operated at a 1/2 gpm peak flow rate. The credible release quantity is estimated at 1 gallon (0.5 gpm X 2 minutes).

5. VAFB Titan IV launch facilities have fixed propellant supply lines installed at some clean room levels.

a. It is possible to eliminate the use of drum containers by attaching the propellant service panel directly to the fixed fuel line connection points using flexible stainless steel hose sections (Figure X-6).

b. Bulk propellant is drawn from two possible locations: The Launch Support Building (LSB) fuel transfer room or the fuel trailer pad, located outside and adjacent to the LSB fuel transfer room.

c. A 3/8 inch diameter, 10- to 15-foot flexible hose sections are typical connections between the fixed propellant supply system and the payload.

d. Propellant service panels are normally operated at a 1/2 gpm peak flow rate. The credible release quantity is estimated at 1 gallon (2 minutes X 0.5 gpm).

G. ESTIMATED DYNAMIC TRANSFER ACCIDENTAL RELEASE QUANTITIES - LAUNCH VEHICLE FUELING OPERATIONS

1. CCAS and VAFB Delta Launch Vehicle Fuel/Defuel Operations

a. Fuel and oxidizer are delivered to the launch pad in 2,500-gallon mobile trailers. The trailer is connected to the launch tower propellant transfer system by flexible stainless steel hose sections, as depicted at Figure X-7.

b. Flexible hose sections from the tanker to the fixed propellant manifold on the umbilical tower, typically, are 1 1/4- inches in diameter and 20-feet in length

c. Fuel and oxidizer transfer is conducted at a peak flow rate of 20 gpm. The credible release quantity is estimated at 40 gallons (2 minutes X 20 gpm).

d. Stage II fuel and oxidizer tanks are connected to fixed umbilical tower propellant distribution systems by means of flexible stainless steel hose sections. Fill, fill purge, return and bleed lines are connected during transfer operations. Flexible hoses are 3/4-inches in diameter and 15 feet in length. The credible release quantity is estimated at 40 gallons (2 minutes X 20 gpm) for a leak at this level.

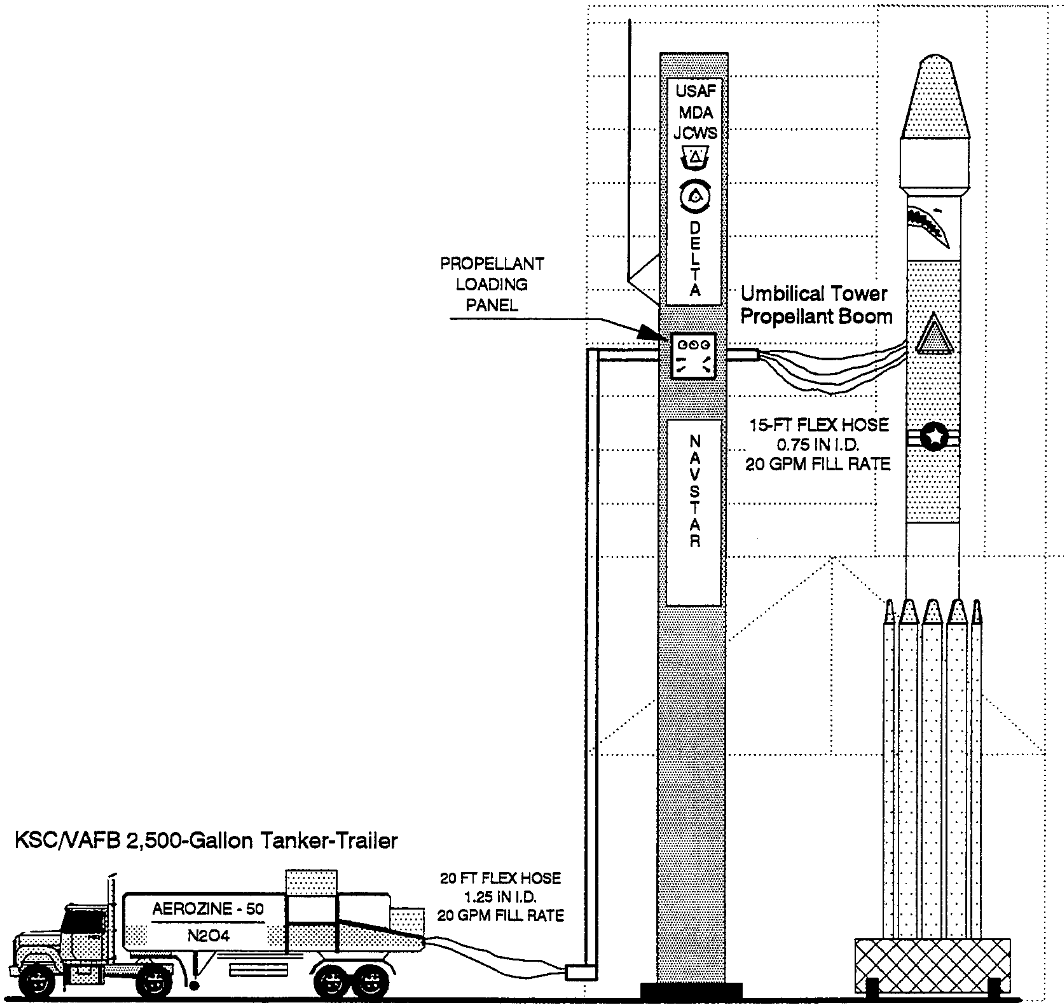


Figure X-7. Delta Launch Vehicle Fueling Schematic.

2. CCAS and VAFB Titan Launch Vehicle Fuel/Defuel Operations

a. Fueling/defueling operations are conducted for Titan Stage 0 (TVC), Stage I, and Stage II. A-50 and oxidizer are pumped from ready storage vessels (RSVs) located in the fuel and oxidizer holding areas (FHA/OHA). Propellants are transferred through fixed distribution systems from the FHA/OHA to umbilical tower (UT) fixed manifolds, as depicted in Figure X-8. The connection from the UT manifold to the launch vehicle is by flexible stainless steel hose lengths.

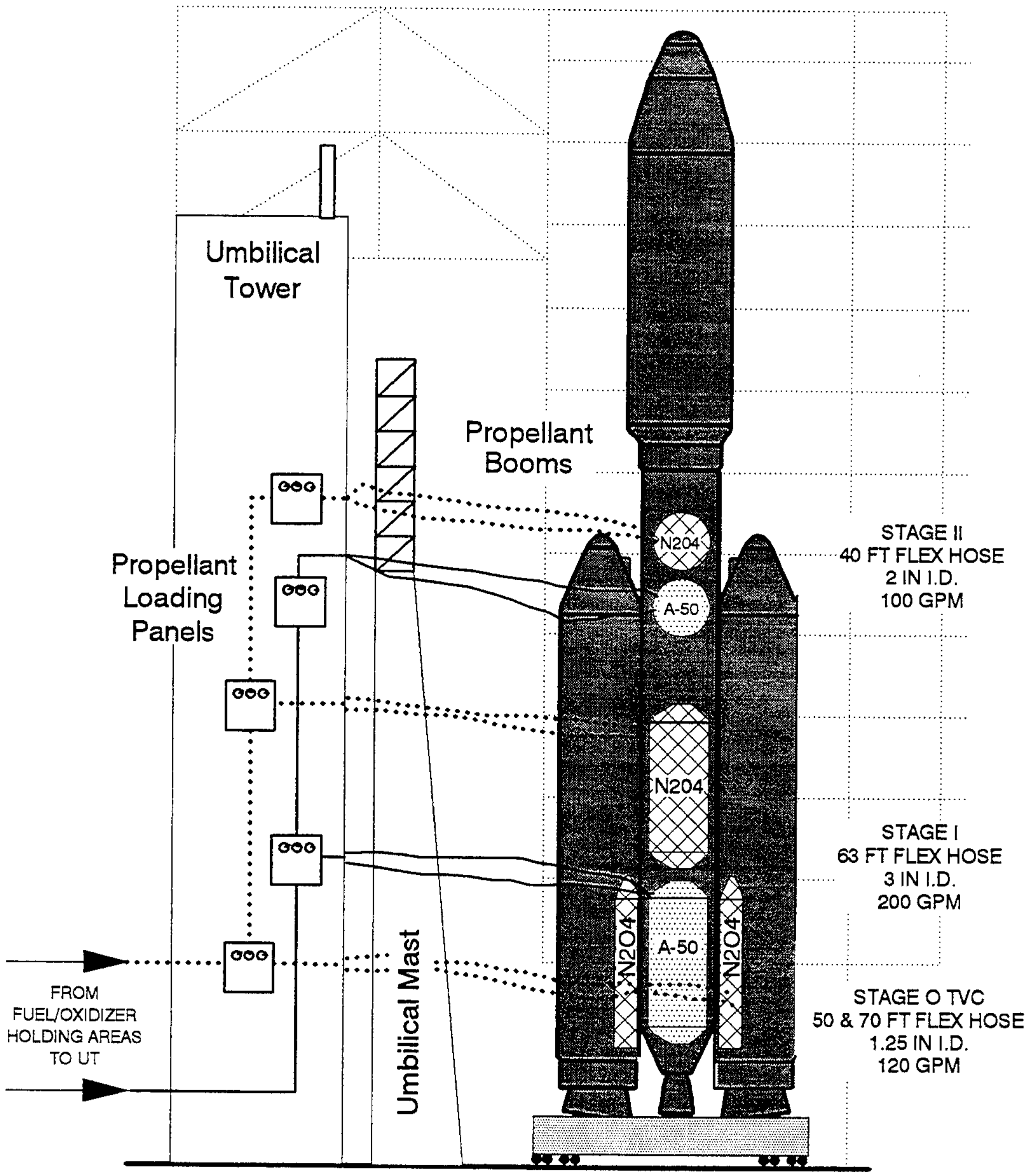


Figure X-8. Titan Launch Vehicle Fueling Schematic.

b. Table X-1 defines Titan IV propellant transfer system hardware data and estimated release quantities.

Table X-1. Titan IV Propellant Transfer Release Data.

Vehicle Location	Hose Length (ft)	Hose Diameter (in)	Transfer Rate (gpm)	Release Quantity (gallons)
Stage I	63	3	200	400
Stage II	40	2	100	200
TVC Tanks	50	1.25	120	240
	70	1.25	120	240

H. SUMMARY

1. Estimated release quantities for accidents that are assumed to occur during dynamic propellant transfer operations at CCAS and VAFB are summarized at Figure X-9. Transfer operations at both bases are, essentially, equal. Minor differences in flexible stainless steel transfer hose diameters and lengths, as well as small differences in propellant transfer unit flow rates, account for the deviations in release quantities between the CCAS and VAFB systems.

2. Propellant transfer accidental release quantities were estimated to range from 1-gallon to 400 gallons.

3. A hypergolic propellant release in the 100- to 400-gallon range that ignites will create a significant fire area. The VAFB and CCAS fire departments should have the capability to effectively suppress and extinguish fires of this size using both crash vehicle turrets and hydrant-supported hand lines.

4. Extinguishment is expected to be much more difficult than it is for jet fuel fires. Much larger quantities of agent and water will be required. Frequent resupply of crash vehicles (P-19/P-23), firefighters, and extended hydrant-sourced applications may be required. Fire fighters must wear OSHA Level A, fully-encapsulated ensembles, if they conduct any on-foot, hand line applications or rescue operations in the proximity of toxic propellant vapors and combustion products .

5. Larger releases beyond 400 gallons are possible, but their probabilities are considered remote. Very large releases, most likely, would be associated with a catastrophic accident involving the loss of a launch vehicle or bulk storage facility.

HYPERGOL END USE LOCATION/HYPERGOLIC PROPELLANT TRANSFER OPERATION	LAUNCH SYSTEM HYPERGOLIC FUEL & OXIDIZER TANK CAPACITY (GALLONS)				PROPELLANT TRANSFER UNIT (PTU) HARDWARE SPECIFICATIONS				
	A-50	N2H4	MMH	N2O4	X-FER HOSE DIA. (IN.)	X-FER HOSE LENGTH (FT.)	HOSE VOLUME (GAL.)	X-FER RATE (GPM)	MAJOR RELEASE GPM X2 MIN (GAL.)
DELTA II LAUNCH VEHICLE									
STAGE 2 UT PROPELLANT TRANSFER SYSTEM	622			724	0.75	15	0.34	20	40
STAGE II FILL SUPPLY TANKER-TRAILER 2,500-GAL LIQUID TANKER	2,500			2,500	1.25	20	1.84	20	40
MST PAYLOAD PROCESSING 30 GAL CONTAINERS/55 GAL DRUMS		30-250+	30-250+		0.375	10	0.06	0.5	1.0
ATLAS-CENTAUR LAUNCH VEHICLE									
CENTAUR RCS 30 GAL CONTAINERS/55 GAL DRUMS		40			0.375	10	0.06	0.5	1.0
MST PAYLOAD PROCESSING 30 GAL CONTAINERS/55 GAL DRUMS		30-250+	30-250+		0.375	10	0.06	0.5	1.0
TITAN IV LAUNCH VEHICLE									
STAGE 0 TVC (2 TANKS) UT PROPELLANT TRANSFER SYSTEM				1,792	1.25	50 70	3.19 4.46	120	240
STAGE 1 UT PROPELLANT TRANSFER SYSTEM	15,950			19,020	3.00	63	23.13	200	400
STAGE 2 UT PROPELLANT TRANSFER SYSTEM	3,780			4,220	2.00	40	6.53	100	200
CENTAUR RCS 30 GAL CONTAINERS/55 GAL DRUMS		40			0.375	10	0.06	0.5	1.0
MST PAYLOAD PROCESSING 30 GAL CONTAINERS/55 GAL DRUMS		30-250+	30-250+		0.375	10	0.06	0.5	1.0
CCAS RSV FILL A-50 (2,500 GAL TANKERS) N2O4 (10,000 GAL RAIL CARS)	 2X11,000 			 27,000	 1.25 2.00 X 2	 20 20 X 2	 1.27 3.26 x 1	 100 100	 200 200
VAFB RSV FILL (A-50 & N2O4) SLC-4E (2,500 GAL TANKERS) SLC-4W (2,500 GAL TANKERS)	 25,200 2 x 15,000			 28,000 28,000	 3.00 3.00	 20 20	 7.34 7.34	 150 150	 300 300
PAYLOAD PROCESSING FACILITIES									
55 GAL DRUMS		55-250+	55-250+		0.375	10	0.06	0.5	1.0
30 GAL DRAIN CONTAINERS		30-250+			0.375	10	0.06	0.5	1.0
2,000 LB SA-ALC CYLINDERS				250 +	0.375	10	0.06	0.5	
PROGRAM-SPECIFIC GSE		250 +	250 +	250 +	0.375	10	0.06	0.5	1.0

Figure X-9. CCAS and VAFB Estimated Hypergolic Propellant Transfer Release Database.

6. This analysis did not establish any data that would support a catastrophic release scenario. Should such an accident occur, the fire department would not have the capability to directly mitigate the fire and vapor effects of the propellants. More likely, their role would be for rescue and to minimize fire spread and collateral damage. Fire fighter readiness and training in these areas is readily maintained via suppression and rescue exercises for the propellant release scenarios identified in this analysis that are in the 100- to 400-gallon range.

SECTION XI

HYPERGOLIC PROPELLANT-JUSTIFIED OPERATIONAL REQUIREMENTS DOCUMENTS FOR IMPROVED FIRE DEPARTMENT CAPABILITIES

A. INTRODUCTION

1. In Phase I of this technical effort, a knowledge base analysis was conducted to identify the operational and technical parameters that defined the space-launch uniqueness of the CCAS and VAFB fire department missions. The fundamental differences between these two organizations and their Air Force counterparts is their requirement to be equipped and trained to respond to the accidental releases of large quantities of hypergolic propellants. Additionally, they must identify and enforce life safety, fire prevention, and emergency response standards in the very unique support facilities that are required to assemble and process launch vehicles and payloads.

2. In Phase II, hazard analyses were conducted to determine the mechanisms and locations of accidents on CCAS and VAFB that would involve the release of hypergolic propellants and, consequently, trigger a fire department emergency response. The objective was to determine the magnitude and relative probability of occurrence of credible hypergolic release incidents. This information was used to quantify and justify required fire department operational capabilities. The final listing of fire department operational requirements was validated and prioritized by the Air Force Space Command (AFSPC) fire protection community.

3. Operational requirements documents for each validated requirement were prepared and delivered to HQ AFSPC during Phase III of this technical effort.

B. CCAS AND VAFB FIRE DEPARTMENT SPACE LAUNCH SUPPORT MISSION-UNIQUENESS

1. The CCAS and VAFB fire departments are the only two units in the USAF that must be equipped and trained to respond to accidental releases and fires involving very large quantities of highly toxic hypergolic fuels, hydrazine and its derivatives, and nitrogen tetroxide, a hypergolic oxidizer. Their mission is to provide structural, crash, rescue, and fire prevention capabilities for the launch support facilities, space launch vehicles, payloads, and hazardous propellant storage and transfer facilities involved in United States Air Force (USAF) and commercial satellite launch operations.

2. Hydrazine-based fuels are used in small quantities at bases supporting F-16 and B-2 APU systems. However, special fire fighting agent requirements have not been identified for these fire departments by their operational commands.

C. HAZARDOUS PROPERTIES OF HYPERGOLIC PROPELLANTS

CCAS and VAFB fire department emergency response operations involving hydrazine fuel or nitrogen tetroxide oxidizer can involve the simultaneous exposure to both the flame and toxic effects of these chemicals.

1. The Hydrazine Fuels

a. Anhydrous Hydrazine, AH (N_2H_4), and its derivatives, monomeythlhydrazine, MMH (CH_6N_2), unsymmetrical dimethylhydrazine UDMH ($C_2H_8N_2$), and Aerozine 50 (A-50), a 50:50 percent mixture of AH and UDMH, are extremely toxic by inhalation and skin contact routes.

b. Hydrazine burns at a rate that is about 10 times as fast as a hydrocarbon fuel fire. Therefore, it is more intense and spreads faster. Hydrazines spontaneously and violently react when contacted with oxides, such as rust, dust and debris, flame or spark.

2. The Oxidizer, Nitrogen Tetroxide

a. Nitrogen Tetroxide (N_2O_4) is not flammable. However, when added to a fire, it enriches the fire intensity of combustion and burning rate by providing an additional oxygen source.

b. Nitrogen tetroxide and its vapors explode on contact with hydrazine fuels, amines and furfuryl alcohol. Additionally, it can cause ignition on contact with wood, paper and hydrocarbon fuels.

c. Oxidizer-enriched fires will produce more heat and be more difficult to extinguish. Intense white flames can be produced. The smoke signature produced is that normally associated with NFPA Class A (wood & paper products) and B fires (hydrocarbon fuels).

d. Nitrogen tetroxide is extremely toxic, and presents a serious health risk through skin and eye contact, and inhalation routes. It reacts with skin moisture and with water in the lungs to produce nitric and nitrous acids that destroy contacted tissues.

D. SUMMARY OF HYPERGOLIC PROPELLANT RELEASE SCENARIOS

1. The primary causes of hypergolic chemical release and potential fires at CCAS and VAFB that would require fire fighter suppression and rescue response are accidents during lift vehicle and payload processing operations. These normally occur during the transfer of propellant chemicals from bulk or mobile storage containers into a launch vehicle or payload on-board fuel tank.

2. Accidental releases of hypergolic propellants on CCAS and VAFB were assumed to result from incidents involving propellant containers, mobile tanker-trailers, and/or the transfer equipment used to pump and distribute the commodities from one container to another, or into the launch vehicle and payload on-board tanks.

3. Nine accidental hypergolic chemical release hazard scenarios resulting from common space launch system processing and support operations at CCAS and VAFB were identified. These scenarios represent a spectrum of generalized hypergolic chemical/fire threats facing the CCAS and VAFB fire departments. Each can generate a fire department requirement to provide fire suppression, rescue and/or HAZMAT emergency response, or a combined fire-HAZMAT operation. They are listed in their order of assumed probability, from the most likely to the least likely.

a. Accident during propellant storage container sampling operation

The release mechanisms are over-filled glass sample bottles, dropped glass sample bottles, and the improper seating of sample draw equipment connections.

b. Accident during propellant container or mobile tanker maintenance

The propellant is released when an access port or container penetration component at or near the bottom of the container is removed with residual chemical remaining. This causes the gravity flow of the propellant on to the pavement or ground below.

c. Propellant transfer accident at bulk storage facilities

Four release mechanisms are assumed:

(1) The improper seating of stainless steel hose disconnect hardware with additional hose lengths or the fixed connection points of the mobile tanker or bulk storage facility.

(2) Leaks through a breach in a stainless steel hose section or in a fixed distribution system component. These can be caused by temperature stresses and displacements, thermal fatigue or reactive chemical - induced deterioration and subsequent material failure under transfer pressures.

(3) Deterioration, material fatigue, cathodic erosion, temperature-induced displacements, and improper maintenance of a propellant transfer system component, such as a valve, flowmeter, pipe or connection fitting that results in a material failure or joint separation.

(4) Human factors. Failure to comply with official procedures could result in the routing and transfer of propellants to a non-authorized destination. Examples include vent pipes or open sump areas.

d. Propellant release accident during launch vehicle fueling or defueling operations

Four release mechanisms are assumed:

(1) The improper seating of stainless steel hose disconnect hardware with additional hose lengths or the fixed connection points of the mobile tanker or bulk storage facility.

(2) Leaks through a breach in a stainless steel hose section or in a fixed distribution system component. These can be caused by temperature stresses and displacements, thermal fatigue or reactive chemical - induced deterioration and subsequent material failure under transfer pressures.

(3) Deterioration, material fatigue, cathodic erosion, temperature-induced displacements, and improper maintenance of a propellant transfer system component, such as a valve, flowmeter, pipe or connection fitting that results in a material failure or joint separation.

(4) Human factors. Failure to comply with official procedures could result in the routing and transfer of propellants to a non-authorized destination. Examples include vent pipes or open sump areas.

e. Accidental release during propellant transfer operations in payload processing facility clean rooms

Four release mechanisms are assumed:

(1) The improper seating of stainless steel hose disconnect hardware with additional hose lengths or the fixed connection points of the mobile tanker or bulk storage facility.

(2) Leaks through a breach in a stainless steel hose section or in a fixed distribution system component. These can be caused by temperature stresses and displacements, thermal fatigue or reactive chemical - induced deterioration and subsequent material failure under transfer pressures.

(3) Deterioration, material fatigue, cathodic erosion, temperature-induced displacements, and improper maintenance of a propellant transfer system component, such as a valve, flowmeter, pipe or connection fitting that results in a material failure or joint separation.

(4) Human factors. Failure to comply with official procedures could result in the routing and transfer of propellants to a non-authorized destination.

f. Roadway vehicle accident involving propellant containers or tanker-trailers

The release mechanism is assumed to be a puncture or break in the portable hypergolic propellant container or tank that results from damage sustained in a transportation vehicle accident.

g. Loading or unloading accident involving a dropped propellant container

A puncture or break in a portable hypergolic propellant container is assumed to result from damage sustained in a container loading/off-loading accident.

h. Vehicle accident involving propellant sample containers

Assumed release mechanisms are broken glass sample bottles. Exterior carrier containers are assumed to have broken open. The propellants are assumed to be released at the accident site.

i. Transportation or mating accident involving a fueled satellite payload

The assumed release is caused by impact or shock to the payload propellant system from the accident situation. This would then cause a break or separation failure (such as at a weld or pipe connection) in an on-board tank or distribution line. Propellant would escape under pressure to the surrounding area. The propellant could be contained within the satellite's transportation shroud or released to the open air in a clean room or at an outdoor accident site.

E. OPERATIONAL REQUIREMENTS IDENTIFICATION AND VALIDATION PROCESS

1. An operational requirements review and validation meeting was held at the CCAS fire department on 26 April 1994. Accidental propellant release scenarios and their corresponding fire department emergency response requirements were presented to the AFSPC fire protection community. The operational requirements review panel consisted of:

- The Patrick AFB Fire Chief. He is responsible for all fire protection matters at CCAS.
- The Vandenberg AFB Fire Chief.
- The Cape Canaveral Air Station Fire Chief. He is an employee of the Johnson Controls' Launch Base Support (LBS) Contract.
- The HQ AFSPC Fire Protection Functional Manager.
- The HQ AFSPC Chief of Civil Engineering Readiness Requirements.

2. The panel assessed current procedures and assets to deal with the hypergolic propellant fire and vapor threats that were defined by the hazard analysis. Seven specific operational requirements for increased fire department capabilities were validated. Of these, three were validated for fire department use during propellant-related emergency response operations. Two were validated for the early detection of propellant vapor and flame threats. One operational requirement was validated to identify OHSA-compliant means of egress from mobile service towers (MST) during emergencies. The seventh validated operational requirement was to develop OSHA-compliant emergency response plans and procedures for launch tower clean room occupants.

3. Five of the validated operational requirements cannot be purchased from off-the-shelf sources and will require research, development and acquisition (RD&A). Two requirements can be met from current technology sources.

F. FIRE DEPARTMENT OPERATIONAL CAPABILITIES REQUIRING RD&A

1. Volume II of this technical report contains five draft Operational Requirements Documents (ORDs) that were prepared and delivered to the Air Force Space Command Civil Engineer. The ORD is a formatted statement that contains operational performance and effectiveness parameters for a proposed system or concept. ORDs help ensure that the Air Force articulates, validates, budgets, develops, produces and fields military systems that meet the mission and training needs of all users. They are "living" documents, and are updated frequently, as specific operational parameters are identified and proposed system technologies mature.

2. The five fire department operational capabilities that require RD&A are identified below. They are listed in the priority order established by the AFSPC fire protection community, as follows:

a. A combined fire fighter/HAZMAT protective ensemble with body cooling for sustained fire fighting and rescue operations in a dual threat hypergolic propellant fire and toxic vapor environment.

b. Hydrazine vapor detection capable of incipient leak identification in the 1 - 25 parts per million (ppm) concentration range.

c. An additive to water, foam and dry chemical fire extinguishing agents that produces a visible flame and/or smoke when applied to a hydrazine fire.

d. False-alarm immune hydrazine flame detection.

e. Optimization of fire extinguishment parameters and capabilities for current technology agents, such as water, dry chemicals and foams (including acrylic-modified foams) based on large fire (400 gallons/5,000 square feet) experiments.

G. OFF-THE-SHELF FIRE DEPARTMENT REQUIRED OPERATIONAL CAPABILITIES

Two operational requirements that are not within current fire department inventory capabilities, but can be obtained from off-the-shelf technologies were validated. They are:

1. Launch Tower Clean Room Facility Life Safety and Emergency Egress

a. Mobile Service Tower (MST) clean rooms must be configured for safe and rapid means of egress from high elevation hazard areas. Requirements are specified in OSHA 29 CFR 1910, *Occupational Safety And Health Standards*, Subpart E - *Means of Egress*. This entire subpart is promulgated from NFPA 101, *Life Safety Code*.

b. Clean Room Means of Egress Requirements.

(1) A detailed *Standards Compendium* of Federal and Air Force life safety code provisions that are applicable to clean room facility means of egress issues was prepared in briefing format.

(2) Additionally, an explanatory briefing package, entitled *45th Space Wing Launch Site Fire Protection & Life Safety Requirements Analysis,* was prepared. This presentation identified key issues associated with launch tower life safety. It also presented a proposed methodology to conduct launch site life safety hazard analyses. The objective of the analysis process was to identify and document CCAS launch tower requirements for minimum compliance with Federal law.

(3) These two briefing packages were presented to the CCAS Atlas, Delta, and Titan launch squadron staffs during Phase III of this technical effort. Volume II of this technical report contains both documents.

c. Launch Tower Emergency Egress System.

Volume II contains a draft purchase description (PD) for a portable emergency escape chute. This document was delivered to the HQ AFSPC Civil Engineer.

2. OSHA-Compliant Emergency Actions For MST Clean Room Personnel Involved In An Accidental Hypergolic Propellant Release

a. Standards are defined in OSHA 29 CFR 1910.38, *Employee emergency plans and fire prevention plans*, and OSHA 29 CFR 1910.120(q), *Emergency response to hazardous substance releases*.

b. A draft contractor HAZMAT Emergency Response Plan was delivered to the HQ AFSPC Civil Engineer. It contains OSHA-compliant plans and procedures for civilian contractors and their employees who participate in MST clean room propellant transfer hazardous operations. This Plan is provided in Volume II of this technical report.

H. DRAFT OPERATIONAL REQUIREMENTS DOCUMENT SUMMARIES

1. Combined Fire Fighting and HAZMAT Ensemble With Body Cooling

a. Basis Of Operational Requirement

(1) CCAS and VAFB fire fighters urgently need specifically-designed personal protective equipment (PPE) for fire fighting operations involving exposure to the combined flame and the highly toxic liquid and vapor effects of hypergolic propellants.

(2) These chemical mixtures can be deadly and are extremely dangerous. A combined fire fighting/HAZMAT ensemble with body cooling is required to provide:

- Fully-encapsulated liquid and vapor chemical protection.
- Proximity flame and heat protection.
- Body heat removal for extended operations in a toxic environment.

(3) This ensemble will enable the CCAS and VAFB fire departments to safely conduct effective fire fighting and rescue operations in a combination threat flame and toxic propellant chemical environment with minimum manpower.

(4) Current fire fighter reflectorized bunker ensembles do not provide the full encapsulation required by OSHA for protection against the propellant toxic vapors. Additionally, current inventory fully-encapsulated fire fighter HAZMAT suits will melt in the proximity of a fire.

(5) Furthermore, existing fire fighter and HAZMAT ensembles provide no external source for body cooling. This limits fire fighter productivity and capability for strenuous tasks, such as fire fighting and rescue operations, to about 15 to 20 minutes of continuous operations, because of dehydration and heat exhaustion effects.

(6) This capability is an immediate requirement, since CCAS and VAFB launch operations are projected to continue to increase over the next several years. These operations will result in increases of the frequency of hypergolic propellant transportation, transfer and use in launch vehicles and payloads. In turn, these hazardous operations will increase the overall probability

of an accidental release with the potential for a fire situation to result.

b. Shortcomings of Existing Systems

(1) Hypergolic Propellant Fire Response Scenario

The following credible operational scenario depicts the severe threat environment faced by CCAS and VAFB fire fighters: a combined toxic chemical release with fire. Current fire fighter protective ensembles do not provide a combined HAZMAT-flame protective capability or body cooling to prevent heat exhaustion and dehydration from strenuous exercise in a heavy, insulating ensemble.

(a) Fire fighters responding to a hydrazine or hydrazine derivative fire will have to deal with an almost invisible fire that produces little or no smoke. They will have extreme difficulty in determining where the fire boundaries are, the total fire size and the rate of fire spread. Additionally, they will be exposed to a highly toxic chemical atmosphere caused by both the non-combusted hydrazine fuel in the area, as well as the toxic products of combustion from the fire source.

(b) Unless there is an eyewitness account, it will be very difficult to pinpoint the source of the released hydrazine fuel and the flow mechanism, such as gravity-fed or pressurized leaks. Therefore, fire fighters can impinge on a dual threat area consisting of both fire and toxic vapor hazards, without any visible warnings.

(c) Following initial agent application, reignition from hot metal surfaces or fire burn-back from foam decay can occur, or secondary fires involving collateral materials, vehicles or facilities may be ignited by the hydrazine fire. "Invisible" pockets of hydrazine fires will continue to burn until permanently extinguished or until the fuel source is depleted.

(d) Toxic vapors will continue to be produced by both the released chemical and by combustion products in the event of a fire.

(e) Rescue attempts will be similarly dangerous. Incomplete or partial extinguishment can leave several pocket fires in the path of rescue personnel. These will also be virtually invisible if hydrazines are involved. Fire fighters can unexpectedly enter a fire area they did not know was there on their way to or from a rescue site with or without a rescue victim in tow. Because of the usually windy conditions associated with the California and Florida coastal locations of USAF launch sites, such a

situation would be extremely dangerous for larger fires in the 100 - 400 gallon or larger range.

(f) Accidental spills of hypergolic oxidizer, nitrogen tetroxide, are not expected to produce a fire response requirement for CCAS and VAFB fire departments. However, extensive fire fighter emergency response support may be required for search and rescue operations, as well as for foam agent application for toxic vapor suppression.

(g) The fire fighting objective in an oxidizer release response is to prevent spontaneous combustion of other fuel sources, such as hydrocarbons, engine exhausts and organic combustibles, that may come into contact with the nitrogen tetroxide liquid or vapors. All fire fighter responses to oxidizer releases must be treated as a HAZMAT emergency response. Accordingly, fire fighters must be protected to the OSHA Level A standard (29 CFR 1910.120, Appendix B) that requires the wear of a fully-encapsulated ensemble and SCBA.

(2) The current inventory Air Force structural and crash firefighting ensembles do not fully protect fire fighters from the vapor and liquid contact effects of hypergolic propellants or the increased flame temperatures associated with hydrazine and oxidizer-enriched fires. Most hypergolic chemical release scenarios involve pressurized propellant transfer systems, therefore, CCAS and VAFB fire fighters are most likely to conduct operations in the proximity of a pressurized leak source where liquid or vapor contact are highly probable.

(3) Hypergolic chemical skin contact and inhalation threats to fire fighters produce severe health hazards. Nitrogen tetroxide liquid or vapor contact with skin moisture results in the formation of burns and potential blood transfer. Also, it reacts with moisture in the lungs to produce nitric and nitrous acid that destroy contacted tissue. Similarly, liquid hydrazine may penetrate the skin and produce severe effects at high doses. Both hydrazine vapors and the combustion products of hydrazine fires are extremely toxic.

(4) Fire department response to the accidental release of hypergolic propellants, with or without the presence of a fire, is classified as a ***Hazardous Material Emergency Response,*** as defined by OSHA 29 CFR 1910.120 (q) and implemented in NFPA 471, *Responding To Hazardous Materials Incidents*.

(a) Because hypergolic propellants are highly toxic via inhalation and skin contact routes, OSHA and NFPA require Level A protection ("To be selected when

the greatest level of skin, respiratory and protection is required") for CCAS and VAFB fire fighters conducting emergency operations in their presence.

(b) The major fire fighter ensemble components to provide this level of protection are a totally-encapsulating chemical protective suit and a positive pressure, full face-piece self-contained breathing apparatus (SCBA) that is worn inside the encapsulating suit.

(c) Current Level A HAZMAT ensembles used by USAF fire departments are not flame- and heat-resistant, and, therefore, are not useable for CCAS and VAFB hypergolic propellant release incident response.

(5) An additional shortcoming of the existing fire fighter ensemble is the limited sustainability of the individual during a HAZMAT or fire response due to heat stress/fatigue.

(a) Fire fighter response to hypergolic chemical incidents at CCAS and VAFB will be conducted in accordance with OSHA/NFPA protocols for incident command and management. These include the requirement for strict entry control procedures to the incident site and full decontamination of the firefighter/ensemble following completion of operations in the "hot" zone, or when individual breathing air reserve limits are reached.

(b) Studies have demonstrated that fire fighters produce in excess of 500 watts (400 Kcal/hr) of body heat during strenuous fire fighting and/or rescue operations. Additionally, fire fighter tasks may be conducted in the proximity of a fire environment. This adds both convective and radiant heat energy to the fire fighter inside his protective ensemble. The body's main cooling mechanism is heat loss caused by sweat evaporation.

(c) The current firefighter ensemble permits about 22 percent of the maximum evaporative cooling possible, for a heat reduction of 285 watts (245 Kcal/hr). This is greatly exceeded by the fire fighter's metabolic heat build up, even without considering flame-induced additional heat loadings. Accordingly, heat exhaustion and collapse can occur within 20 minutes, depending on individual tolerances and exertion levels.

(d) Since CCAS and VAFB fire fighter response to hypergolic chemical releases and fires requires a fully-encapsulated ensemble, almost no evaporative body cooling can occur during incident response. This condition further limits firefighter sustainability and capability at CCAS and VAFB.

(6) Current firefighter ensemble weight and bulk further increase the individual's task exertion level and heat buildup. They also limit fire fighter mobility and dexterity. A major factor in fire fighter response to hypergolic chemical release (with or without the presence of fire) can be actions to identify and terminate the release mechanism. These tasks generally require the capability for unrestricted vision and digital dexterity for maximum safety and effectiveness. The current fire-resistant ensemble was not designed for HAZMAT response operations.

c. Capabilities Required

(1) System Performance Parameters

(a) The ensemble outer garment, gloves, boots and helmet must provide proximity heat protection for 5 minutes at 3,000 ^{o} F.

(b) The ensemble must be certified as resistant to anhydrous hydrazine and its derivatives and nitrogen tetroxide. Resistance to hydrocarbon fuels and other hazardous chemicals shall be provided to the maximum extent possible, given availability, cost and supportability considerations.

(c) The ensemble shall meet the following National Fire Protection Association (NFPA) standards:

1 NFPA 1991, Vapor-Protective Suits For Hazardous Chemical Emergencies. 2 NFPA 1992, Liquid Splash-Protective Suits For Hazardous Chemical Emergencies. 3 NFPA 1972, Helmets For Structural Fire Fighting. 4 NFPA 1976, Protective Clothing For Proximity Fire Fighting. 5 NFPA 1973, Gloves For Structural Fire Fighting. 6 NFPA 1981, Open-Circuit Self -Contained Breathing Apparatus For Fire Fighters. 7 NFPA 1971, Protective Clothing For Structural Fire Fighting.

(d) The ensemble's body cooling subsystem shall provide the following capabilities:

1 400 watts per hour of body cooling heat removal. 550 watts per hour of body cooling heat removal is highly desirable. 2 Cooling output must be controllable by the wearer. 3 The cooling system must be self-contained. It must be carried on the body with no connections to external support equipment. 4 1-hour duration of continuous body heat removal at 400 watts per hour. A 2-hour duration and 550 watts per hour body heat removal rate are highly desirable. 5 Body cooling garment coverage: head, torso, biceps and thighs.

(e) The self-contained breathing apparatus (SCBA) must provide a minimum one (1) hour rated duration and meet all requirements of NFPA 1981 for a positive pressure SCBA. A two (2)-hour rated duration is highly desirable.

(f) The combined SCBA and body cooling system, to include storage containers, face plate, body cooling garment and working fluids must weigh less than 60 pounds. The SCBA system alone, to include the storage container, face plate and associated valves and regulators, shall weigh no more than 35 pounds. The SCBA and body cooling system must fit the 5 to 95 percentile of the population.

(g) The SCBA back pack thickness (projection from the user's back) must be no greater than 8 inches. The SCBA back pack and all associated equipment shall be designed with rounded corners and with no projections that would inhibit fire fighter entry into or out of confined spaces in the upright or prone positions.

(h) The ensemble system must provide the capability for the user to communicate with nearby personnel by voice. The communications test requirements of NFPA 1981 must be met. In addition, the system must include an interface to allow the user to transmit and receive voice communications on current fire fighter, hand-held, radios.

(i) The ensemble's head and face protection must provide at least 120 degrees of unobstructed vision.

(j) The entire ensemble, as a unit, and as a series of individual components, must enable fire fighter flexibility and dexterity to perform normal fire suppression, rescue and HAZMAT response operations and tasks. These include walking, crawling, climbing ladders, handling manual and motorized tools and equipment, connecting hose lines and adjusting fire apparatus valves and controls, transporting and operating hand-held hose lines and nozzles, entering, operating and exiting fire fighting vehicles, and operating crash vehicle agent delivery systems/monitors from cab work stations.

(k) The combined fire fighting/HAZMAT ensemble with body cooling must be user-tested under live fire and simulated HAZMAT operational conditions and scenarios prior to design acceptance and authorization for production.

(l) The ensemble system shall include a portable, skid-mounted, resupply system for replenishment of breathing air and body cooling working fluids/gases.

1 The resupply system shall be designed for installation at the fire station and onboard a HAZMAT or other support vehicle. 2 The resupply system shall be capable of fully reservicing the breathing air and body cooling systems to full capacity in no more than 5 minutes. 3. The resupply system shall operate on 110/120 volt, 50 or 60 cycle electrical power.

(2) Logistics And Readiness

The combined fire fighting/HAZMAT ensemble with body cooling must be capable of repeated use, to include exposure to flame, heat and toxic chemicals and decontamination with neutralizing chemicals, during fire fighting, rescue and HAZMAT response operations and training exercises with a minimum of servicing and maintenance.

d. Promising Technologies

(1) Wright Laboratories' Fire Research Group at Tyndall AFB, FL, has sponsored the advanced development and testing of a combined fire fighting/HAZMAT ensemble with body cooling. The prototype ensemble will be delivered during FY 95 and will meet the required operational capabilities specified in subparagraph c, above.

(2) This ensemble consists of the following major items:

- Gallet helmet with integrated:
  - Interspiro face mask.
  - Multi-man communications system.
- Chemfab Challenge 5500 Liquid/Vapor HAZMAT ensemble.
- Gentex aluminized outer garment.
- SuperCritical Air Mobility Pack (SCAMP) providing:
  - 1- to 2-hour breathing air.
  - 1- to 2-hour body cooling.
- Boots & gloves with quick-connect, interlocking rings.

(3) The core technology breakthrough is the SuperCritical Air Mobility Pack (SCAMP) that uses ultra-cold (-160 ^{o}C), compressed air (750 psi) to provide a 1 - 2 hour supply of both breathing air and body cooling in a 30-pound package. The prototype SCAMP backpack is shown at Figure XI-1.

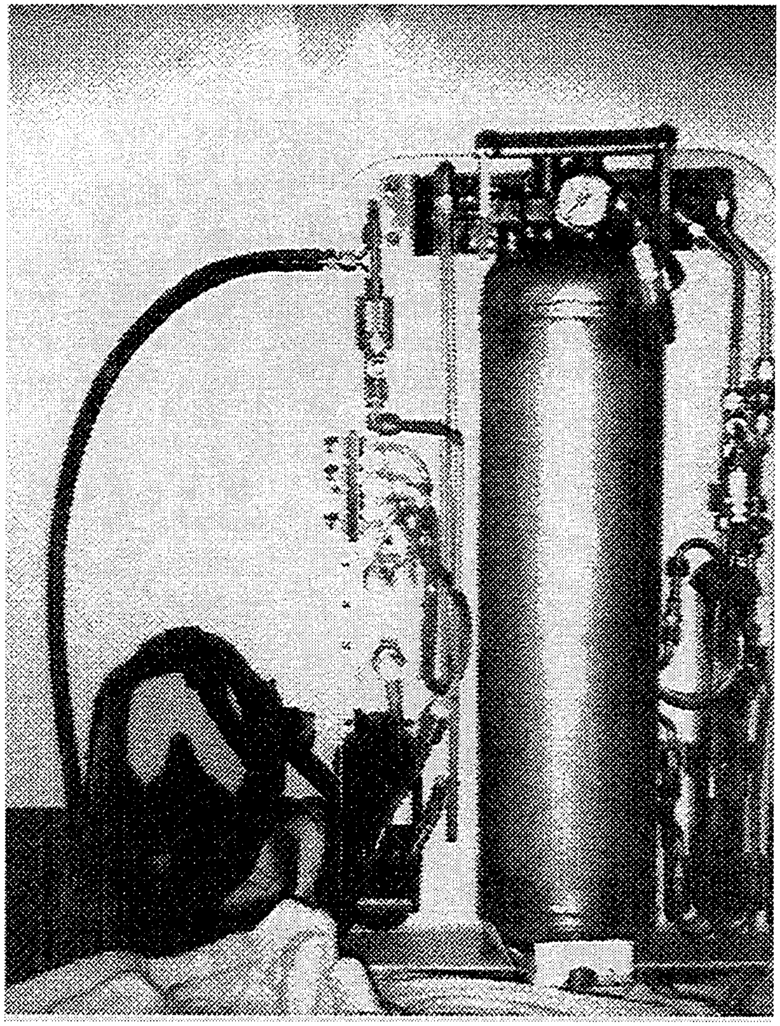


Figure XI-1. Research Prototype SCAMP Back Pack.

(4) The SCAMP body cooling component should provide a significant increase in capability for CCAS and VAFB HAZMAT teams over current fire department 1-hour SCBA systems that have no body cooling capability. Figure XI-2 shows the manufacturer's estimated performance of the system. SCAMP has the potential to fully remove fire fighter body heat that is trapped inside a fully-encapsulated chemical hazard protective garment during strenuous emergency response activities.

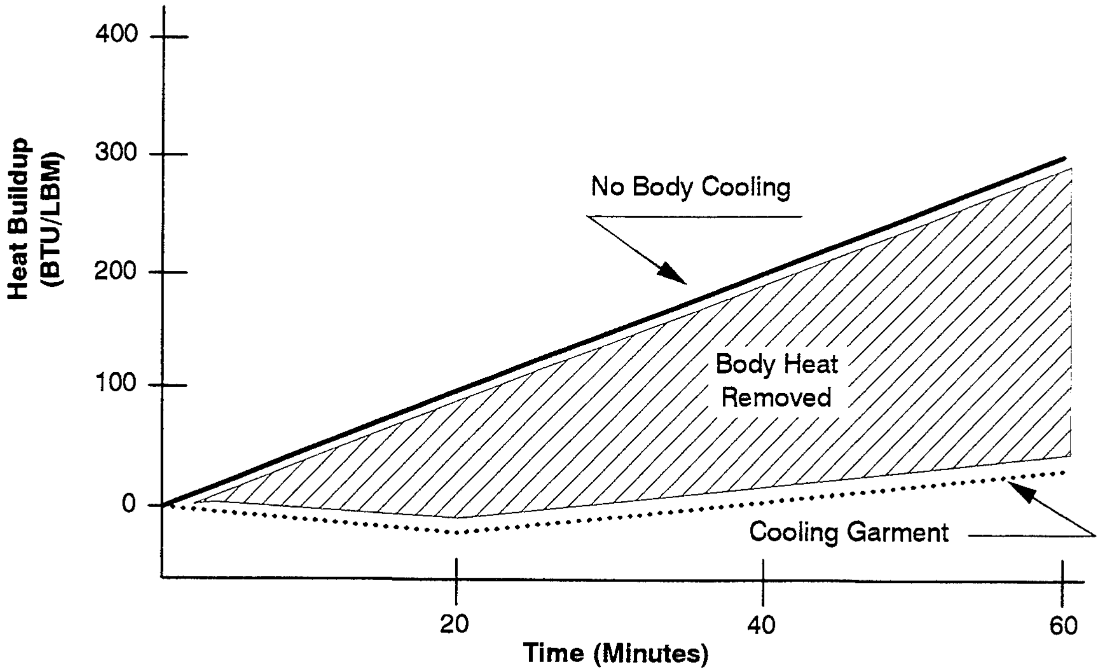


Figure XI-2. SCAMP Body Heat Removal Estimate.

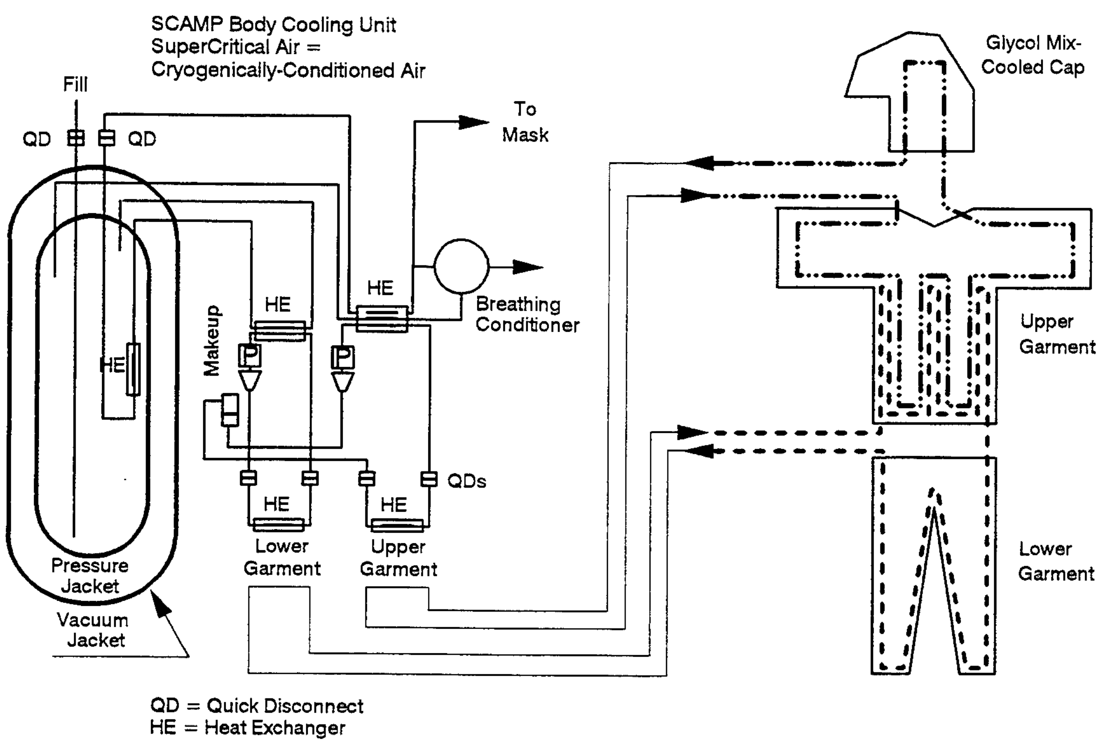


Figure XI-3. SCAMP Breathing Air And Body Cooling System Schematic.

(4) Figure XI-3 shows a schematic of the SCAMP breathing air and body cooling systems. SuperCritical air from the storage dewar is conditioned through a series of heat exchangers and flow regulators to produce breathing air for the fire fighter and cooling energy to the body garment working fluid.

(5) SCAMP storage dewars are estimated to retain operational temperature and pressure for up to 48 hours, before reconditioning is required. Figure XI-4 details the proposed dewar loading system. Two skid-mounted units are recommended for the CCAS and VAFB fire departments. One would be positioned in the main fire station. The second would be installed on a vehicle for SCAMP dewar resupply during fire fighting and HAZMAT emergency response operations.

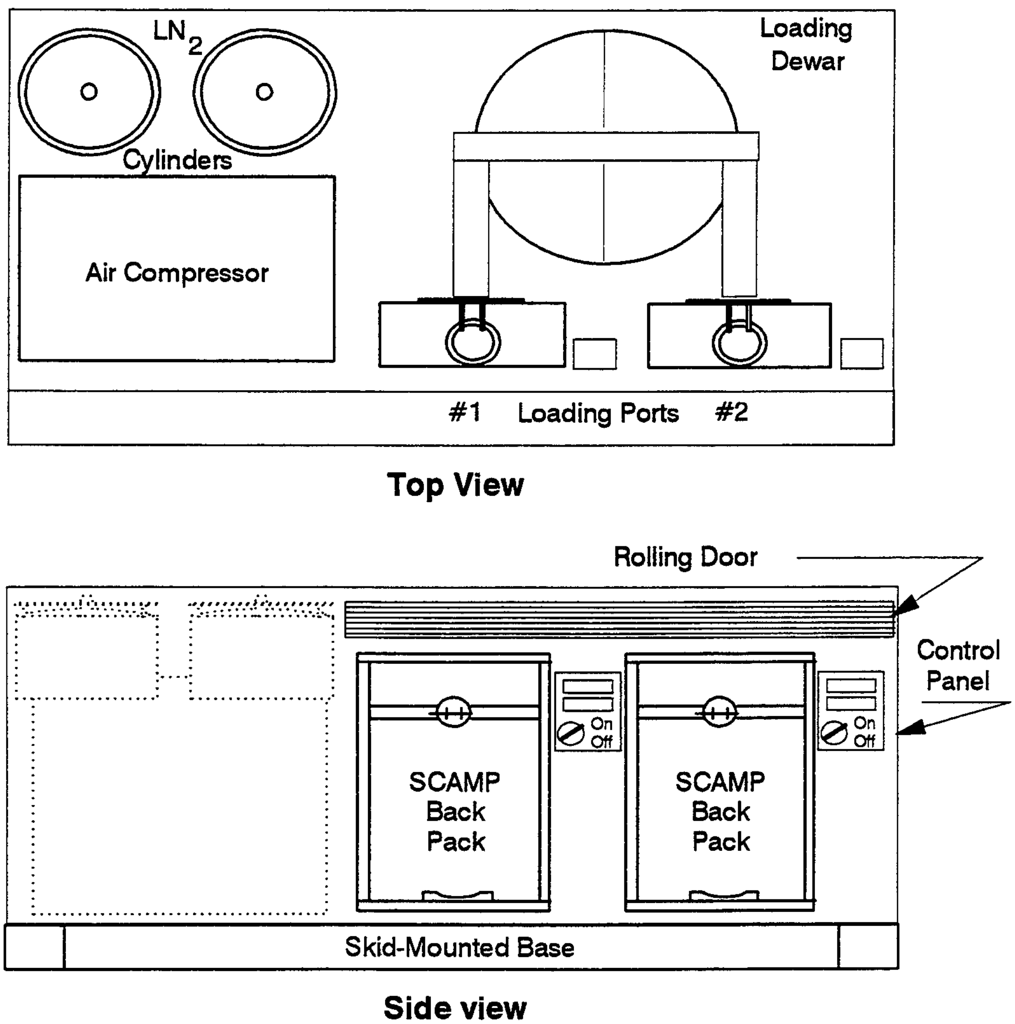


Figure XI-4. Portable SCAMP Dewar Reservicing Unit.

(6) The development and acquisition by the Air Force of the combined fire fighting/HAZMAT ensemble with body cooling will significantly increase the sustainability of CCAS and VAFB fire fighters during emergency response operations involving toxic hypergolic propellants. A preliminary estimate of this increased capability is presented in Table XI-1.

Table XI-1. Experience-Based Estimates of Fire Fighter Performance Vs Protective Ensemble Configuration.

Protective Ensemble	**Typical Task Duration**	**Physiological Effects**	**Recuperation Period**
Current HAZMAT Ensemble W/No Body Cooling Capability	15 min	Heat Exhaustion & Dehydration	4-8 hrs
Fire Fighter/HAZMAT Ensemble W/SCAMP Body Cooling System	60 min	Strong Fatigue/No Dehydration	60 - 120 min

(a) Fire fighter performance effectiveness for sustained strenuous activity is estimated for a person wearing the current HAZMAT ensemble with no body cooling, and for the same person wearing the proposed ensemble with supercritical air and body cooling.

(b) The fire fighter in the current HAZMAT ensemble is estimated to be able to conduct sustained strenuous emergency response tasks, such as casualty rescue and extraction, for 15 minutes. Following this time, body heat build-up inside the ensemble is estimated to cause the onset of heat exhaustion and dehydration. Recuperation from these effects is estimated at from 4- to 8-hours, depending on the age and physical condition of the fire fighter.

(c) The fire fighter in the body cooling garment is estimated to be able to conduct 60 minutes of strenuous emergency response activities. During this time, the SCAMP system will remove most excess body heat from the encapsulating ensemble. The effects of this activity are fatigue and loss of body fluid, however, they are not judged to be debilitating. Recuperation is estimated at 60- to 120-minutes.

(7) A minimum four-fold net increase in fire fighter operational performance is estimated to be gained by the employment of the SCAMP system with body cooling. The basis of this estimate is shown below. The calculation conservatively assumes a fire fighter in the SCAMP ensemble will require 120 minutes for recovery, and the fire fighter in the current HAZMAT ensemble will require 240 minutes. Additionally, ensemble don time is estimated to be 15 minutes and ensemble decontamination and doff time are estimated at a combined 30 minutes. Therefore, the maximum number of site entries for the fire fighter with SCAMP body cooling is limited to two during one 8-hour duty shift.

$$\text{Fire Fighter Performance Increase} = \frac{\text{Body Cooling Emergency Response Time}}{\text{Current HAZMAT Ensemble Emergency Response Time}}$$

$$= \frac{\text{(Body Cooling Site Entry Time) X Entries Per 8-hour Shift}}{\text{(HAZMAT Ensemble Site Entry Time) X Entries Per 8-hour Shift}}$$

$$= \frac{\text{(60-minutes) X (2 site entries)}}{\text{(15-minutes) X (2 site entries)}} = 4X$$

(8) The maximum potential estimated performance increase for the fire fighter body cooling ensemble is estimated, as above, to be 12X for an 8-hour duty shift. This factor is computed by assuming 3 X 60-minute site entries for the fire fighter with body cooling and a single, 15-minute site entry (8-hour recuperation period) for the fire fighter without the proposed ensemble. Given a 1-hour recuperation period, an ensemble don time of 15 minutes and an ensemble decontamination and doff time of 30 minutes, the maximum number of site entries for the fire fighter with SCAMP body cooling is limited to three during one 8-hour duty shift.

(9) Developmental testing and evaluation of the combined fire fighting/HAZMAT ensemble with SCAMP system body cooling is planned for FY 96. This will be conducted under operational fire fighting conditions by the Department Of Defense Fire Protection Academy at Goodfellow AFB, TX.

2. Incipient Leak Hydrazine Vapor Detection System

a. Basis of Operational Requirement

(1) CCAS and VAFB technicians are involved in several hazardous processes where reliable and rapid detection of hydrazine vapors will be essential in preventing major propellant release incidents with consequences of serious injury or death, and the potential for significant facility and environmental damage. These include:

(a) Loading/unloading 2,500 gallon mobile tankers at bulk storage facilities.

(b) Propellant fuel (A-50) off-load at Titan IV ready storage sites.

(c) Titan IV Stage I & II A-50 fueling from on-site ready storage tanks. Delta Stage II launch vehicle A-50 fueling operations are from 2,500 gallon mobile tanker trailers.

(d) Satellite fueling (N_2H_4, MMH & N_2O_4) operations in ground-level or launch tower clean room facilities and Centaur fueling in launch tower clean rooms.

(2) Fires fueled by anhydrous hydrazine and its derivatives produce little or no visible flame and smoke. Technicians involved in hypergolic propellant fuel operations wear fully-encapsulated protective ensembles. These include vision-restricting helmets and face plates.

(3) Because of the near-invisible nature of hydrazine vapors and limited fields of vision, these personnel have extreme difficulties in identifying the location and size of a hydrazine fire, its rate of growth, and direction of spread. Therefore, technician proximity to a hydrazine fire can remain undetected until a very dangerous secondary effect is recognized - the melting of the individual's protective ensemble components.

(4) In such cases, these very dangerous conditions can lead to ineffective use of portable fire extinguishers, delayed or ineffective emergency actions and evacuation to include system shutdown and sounding alarms, as well as technician injury or death. Thus, it is imperative that hydrazine/fuel vapors be detected early, before explosive levels can build up, and before fuel liquid and/or vapors can come into contact with any material that will cause ignition or detonation to take place.

(5) CCAS and VAFB facilities and processes with hydrazine hazards urgently need an automatic vapor

detection system that can reliably detect hydrazine and hydrazine derivative vapors at the leak source during the incipient stage of the release process and warn personnel to take corrective action.

(a) Given this advanced notice, preventive measures can be initiated to identify, isolate and terminate the leak condition, before the release quantity is sufficient to support combustion or vapor phase explosion.

(b) Early incipient leak detection and emergency actions to prevent or mitigate the release of highly toxic and explosive hydrazine fuels combine to form a very capable and effective method of fire and explosion prevention.

b. Shortcomings of Existing Systems

(1) Hydrazine is very explosive at concentrations within a very wide range of explosive limits (2.5% - 98% for MMH), and burns at a rate that is about 10 times as fast as a hydrocarbon fuel fire. It is more intense and spreads faster.

(2) Additionally, hydrazine fires are virtually colorless and smokeless. This is because the carbon-based compounds that are contained in and produced by jet or automotive fuel fires are not present in hydrazines to produce black smoke and the characteristic yellow-orange flame.

(3) Therefore, it is imperative to detect hydrazine leaks at the earliest possible stage of development, during their incipient state when detectable quantities are in the 1 to 25 parts per million (ppm) concentration range.

(4) Current hydrazine sensors are capable of detecting vapor levels associated with major leaks and spills and for detecting explosive concentrations. They are marginally capable of detecting hydrazine vapor concentrations locations needed for incipient (1 -25 ppm) leak detection and rapid emergency response, and may require lengthy sampling times for a single detection point.

(5) Furthermore, current fixed point area hydrazine detection systems are not capable of the sequential monitoring of multiple potential leak points, as is required for incipient leak detection of specific fuel transfer hardware configurations.

(6) The space launch organizations at CCAS and VAFB require the development and acquisition of a

hydrazine incipient leak vapor detection system. It would be used at exterior propellant transfer and storage facilities and inside payload processing clean rooms.

c. Capabilities Required

(1) System Performance Parameters

(a) The hydrazine vapor detection system is envisioned to be a family of detection systems or a system that can be calibrated to react to vapors from each of the hydrazine fuel types, and to take into account the various site-specific chemical background false alarm sources.

(b) Clean Room Hydrazine Vapor Detection

1 The hydrazine vapor detection system will identify a 1 to 25 ppm vapor concentration of anhydrous hydrazine or MMH vapor produced by a calibrated laboratory release simulation apparatus at a 1-ft range under interior USAF ground-level and launch tower clean room equipment, chemical background and ventilation air flow conditions. 2 Anhydrous hydrazine and MMH are typical fuels for military and commercial satellite payloads and Centaur reaction control systems. 3 The detection system shall support a minimum of 8 sampling locations. Sampling shall be sequential from one location at a time. 4 Response time for each sampling location shall be 2 minutes or less.

(c) A-50 Bulk Transfer & Storage Facility Vapor Detection

1 The hydrazine vapor detection system will identify a 1 to 25 ppm vapor concentration from a calibrated laboratory release simulation apparatus at a 1-ft range under outside/exterior CCAS and VAFB fuel storage and transfer facility background weather conditions. 2 Large quantities of A-50 are stored in bulk and transported in mobile trailers to fuel Titan and Delta launch vehicles. 3 The detection system shall support a minimum of 8 sampling locations. Sampling shall be sequential from one location at a time. 4 Response time for each sampling location shall be 5 minutes or less. 5 The system shall be environmentally and impact-hardened for both fixed and portable field/facility applications.

(d) Hydrazine vapor detection systems shall not react/alarm to any background chemicals associated with space launch system, facility or payload cleaning, maintenance or fueling operation.

(e) Hydrazine vapor detection systems shall not react/alarm to any electromagnetic energy sources

(e) Hydrazine vapor detection systems shall not react/alarm to any electromagnetic energy sources associated with space launch system communications or surveillance equipment, or from any transient energy that may be associated with CCAS or VAFB space launch support operations.

(f) System detection of hydrazine vapors shall result in the initiation of area visible and audible alarms/klaxons and the transmission of an alarm status message to both the CCAS/VAFB fire department and one or more TBD launch squadron command and control centers. Alarm hardware and message transmission electronics shall be detection system component subsystems. Alarm messages shall be transmitted by TBD (RF and/or hard wire) data links.

(2) Logistics and Readiness

(a) Clean Room Systems

Hydrazine vapor detection systems in clean rooms shall demonstrate a system availability of 99 percent over a mission time of two years.

(b) Exterior/Outdoor Systems

Hydrazine vapor detection systems protecting outdoors or other non-fully enclosed processes and/or equipment shall demonstrate a system availability of 97 percent over a mission time of two years.

(c) These levels of availability are attainable with appropriate system design considerations of circuit modularity, BIT, and maintenance engineering.

d. Promising Technologies

(1) Laser-Based Detection System

(a) Research began during March 1995 to develop a laser spectrometer-based system for the detection of hydrazine that would be present in vapor releases and flames. This technical effort is being conducted by the Air Force Fire Protection Laboratory at Tyndall Air Force Base, FL. The laser spectrometer is being used to detect hydrazine by observing its transmittance spectral lines. The system would then employ a microprocessor to compare one or more transmittance peaks with known hydrazine spectral information. Initial research is investigating hydrazine spectral signatures in the low (1.0 - 2.0 μm) and mid (2.5 - 10 μm) infrared ranges.

(b) The laser detection system would be configured to pass the beam through a volume of air that is nearby a potential hydrazine leak point. The beam would impact a target sensor, where transmittance data would be determined. Several beam - target systems can be slaved to a common detection microprocessor.

(2) Fourier Transform Infrared (FTIR) Area Vapor Monitor

(a) This detector has been developed and tested by the NASA KSC Toxic Vapor Detection/Contamination Monitoring Laboratory. It consists of a 486 microprocessor-based FTIR instrument and vapor sampling apparatus. The detector is "tuned" to recognize a specific chemical. It is very accurate in the 1- to 25-ppm vapor concentration range. A six-point manifold has been developed to provide a multiple point detection capability.

(b) FTIR technology has been proven at NASA KSC for numerous real-time vapor monitoring applications, including ammonia hypergolic propellants, solvents and Shuttle tile re-waterproofing chemicals. The detector sequentially draws vapors from each sample point into a processing cell. The FTIR instrument then uses interferometry and advanced signal processing to produce a mid-infrared spectrum of the drawn vapors.

1 The mid-infrared spectral region is used, because it is known as the "fingerprint" region for chemical identification.

2 The FTIR looks at large portions of the spectrum to identify the light wavelengths of the chemical that is selected for detection. As a result, it is a true multi-component detector that is much less likely to give false readings due to interference vapors that are normally present, but of no interest to hydrazine or oxidizer detection.

(c) The instrument continuously monitors its own health, and indicates when maintenance is needed. Valid measurements are produced almost immediately upon power-up. Two-way communications allow on-line control of virtually all detector functions. A contact closure can be added to activate alarm circuits, if required. The estimated cost for a single, environmentally-hardened, six-point system, is $100,000.

(3) Hydrazine Vapor Area Monitor (HVAM)

(a) This detector has been developed and tested by the NASA KSC Toxic Vapor Detection/Contamination Monitoring Laboratory. It provides a single point sampling capability in two measurement ranges:

1 Threshold Limit Value (TLV). Detection sensitivity is in the 10- to 1,000-parts per billion (ppb) range. This range is used to alarm personnel who are in the vicinity of toxic chemical containers and who do not wear protective ensembles. A 10 ppb TLV is under consideration by the ACGIH as the maximum 8-hour, time-weighted average, worker exposure.

2 Leak. Detection sensitivity is in the 100 ppb to 10 ppm range. Releases in this vapor concentration range can occur during dynamic propellant transfer operations. Personnel conducting these tasks wear protective ensembles. Therefore, hydrazine detection in this range is to ensure that alarms are sounded, and that steps are taken to maintain the vapor concentration below the lower explosive limit.

(b) HVAM consists of a MDA/Polymetron, three-electrode liquid analyzer typically used for the continuous on-line measurement of 0- to 1,000 ppb hydrazine in boiler feed water. Air samples are drawn from the detection point and are mixed with a very dilute sulfuric acid solution. This mixture is then passed through a 1/4-inch O.D. tube where the hydrazine in the air sample is "scrubbed" into the acid solution. A liquid/air separator then pulls the acid/hydrazine solution away from the air and into the analyzer unit. Here, the sample pH is conditioned to 10.2, or above, and the MDA analyzer performs the amperometric measurement of the hydrazine to determine its concentration in ppb.

(c) The HVAM is a complete system that can operate maintenance-free for 90 days. NASA KSC test results indicate a stable detection baseline with only a 2- to 3-ppb drift over two months of operation. The system has been designed to simplify maintenance and to permit the rapid change-out of the core analyzer system to minimize down time. The estimated cost per unit is $25,000.

(4) Ceramic-Metallic (CerMet) Electro-Catalytic Gas (ECG) Microsensor

(a) This detection system is under development by Argonne National Laboratory's Energy Systems Division. It identifies the individual gases in a gas mixture by their electrical signatures. This is made possible by an innovative combination of CerMet materials,

cyclic voltametry, and neural network signal processing. The sensor is small, 2-mm by 3-mm, and rugged.

(b) The cyclic voltametry technique applies a wide range of voltages to the sensor unit. Each gas in contact with the sensor reacts at a characteristic voltage. The system measures the resulting voltage-current signatures. The neural network is trained to recognize the characteristic signatures of the different gases expected to be in the sample population. Multiple sample point detectors are feasible, and would employ a microprocessor for polling, character recognition, and alarm signal processing tasks.

(c) Current testing indicates that the sensors are sensitive to the detection of hydrocarbons. A Principal Investigator at the Argonne Laboratory indicates that the system should be fully capable of detecting hydrazine in the 1- to 25-ppm range for incipient leak detection.

(d) Detection system costs are to be determined (TBD). The sensor and micro-controller chip cost about $2.00 each. The neural network processor costs for hypergolic propellant leak detection are TBD. Multiple-point sampling system manufacturing costs are TBD, but are expected to be under $1,000.

3. Hydrazine Fire Fighting Agent Luminescence Additive

a. Basis Of Operational Requirement

(1) Fires fueled by Anhydrous Hydrazine and its derivatives are virtually smokeless and emit little or no visible radiation. The essential visual signatures for effective fire suppression and rescue operations involving a "normal" hydrocarbon fire are missing.

(a) Therefore, responding CCAS and VAFB fire fighters will have extreme difficulties in identifying the location and size of a hydrazine fire, its rate of growth and direction of spread.

(b) Firefighter proximity to a hydrazine fire may remain undetected until very dangerous secondary effects are recognized, such as an extreme temperature rise, the combustion of nearby materials and/or the melting of the individual's protective ensemble components.

(c) Such dangerous conditions could lead to ineffective fire extinguishment and/or fire fighter injury or death.

suppression agents (water, foams, dry chemicals, etc.) that will react with hydrazines or hydrazine flames to produce visible flame and smoke. Preferably, the additive would cause hydrazines to burn with a visible flame and produce a recognizable smoke plume. Alternatively, the additive would produce an independent colored flame and smoke, as a result of its combustion within the hydrazine fire.

b. Shortcomings of Existing Systems

(1) Background Data On Hydrazine Fires & Fire Department Response Capabilities:

(a) Hydrazine burns at a rate that is about 10 times as fast as a hydrocarbon fuel fire. Therefore, it is more intense and spreads faster.

(b) Hydrazine fires are virtually colorless and smokeless. This is because the carbon-based compounds that are contained in and produced by jet or automotive fuel fires are not present in hydrazines to produce black smoke and the characteristic yellow-orange flame. There are no smoke and flame warning mechanisms "built in" at the fire scene to alert the fire fighter that he/she is about to enter the very intense and dangerous fire plume, itself.

(c) The CCAS and VAFB fire departments are equipped to fight hydrazine fires with crash vehicles and pumpers. The crash vehicles carry from 1,000 to 3,000 gallons of water/Aqueous Film-Forming Foam (AFFF) on board. Pumpers may carry 500 gallons of water and normally rely on hydrant connections to provide hose streams for fire extinguishment.

(d) Initial fire department response to a CCAS or VAFB hydrazine fire incident will, normally, rely on AFFF application by mobile crash vehicles, until hydrant-fed hand lines can be established. Then joint AFFF-water application can be considered by the on-scene senior fire officer. During the initial minutes of the response, the sole fire fighting capability will be the agent contained in the crash vehicle on-board tanks (1,000 - 3,000 gallons). Crash vehicle turret application rates are from 500 to 750 gallons per minute (GPM). Therefore, only a very few minutes of fire extinguishment time are available early-on for agent application on the fire.

(2) Hydrazine Fire Response Scenario

Combining the factors described in the subparagraphs above, the following scenario results to depict the significant shortcomings of the existing system:

(a) Fire fighters responding to a hydrazine or hydrazine derivative fire will have to deal with an almost invisible fire that produced little or no smoke. They will have extreme difficulty in determining where the fire boundaries are, the total fire size and the rate of fire spread. Unless there is an eyewitness account, it will be very difficult to pinpoint the source of the released fuel and the flow mechanism, such as gravity-fed or pressurized leaks.

(b) Application of AFFF from initial response vehicles may be very ineffective, since target range and position will be very difficult to judge without visual fire signatures. Once on-board fire fighting agent is expended, vehicles must return to a water source for resupply, or must be connected to a fire hydrant, which may or may not be available. Crash vehicle AFFF supplies also must be replenished.

(c) During delays in agent application, reignition from hot metal surfaces or fire burn-back from foam decay can occur, or secondary fires involving collateral materials, vehicles or facilities may be ignited by the hydrazine fire. "Invisible" pockets of hydrazine fires will continue to burn until permanently extinguished or until the fuel source is depleted.

(d) Fire fighters on foot will be placed in additional danger, since they will not enjoy crash vehicle insulating safety and escape speed. With no smoke or flame coloration danger signals, fire fighters may impinge on the fire surface before they realize its location. The danger is compounded, since the fire fighters will not be aware of fire spread direction or rate caused by wind conditions or fuel flow. Note: Hydrogen fires also are colorless and smokeless. Workers in hydrogen refineries hold straw brooms out in front of them to locate suspected fires: when the broom ignites, one fire boundary is located.

(e) Rescue attempts will be similarly dangerous. Fire fighters can unexpectedly enter a fire area they did not know was there on their way to or from a rescue site with or without a rescue victim in tow. Because of the usually windy conditions associated with the California and Florida coastal locations of USAF launch sites, such a situation would be extremely dangerous for larger fires in the 100 - 400 gallon or larger range.

(3) Summary

(a) CCAS and VAFB fire fighters, today, must fight a hydrazine fuel fire almost "blindly" using current inventory fire fighting agents and equipment. This places the fire fighter in increased jeopardy, and significantly increases the fire loss risk to launch site facilities and, possibly, the launch vehicle and payload systems.

(b) Hydrazine fire consequences will depend on the location of the hydrazine release point relative to launch systems or facilities, the speed and accuracy of fire identification and fire department response, and the effectiveness of fire fighting agent application by fire fighters in vehicles and at the end of hose lines.

c. Capabilities Required

(1) System Performance Parameters

(a) The hydrazine luminescence additive will react on contact with or mix with hydrazine and hydrazine derivative fuels to produce a resultant mixture or compound that burns with a flame and smoke plume that are clearly visible under bright sunlight outdoor weather conditions. Visible smoke density and flame intensity requirements are TBD.

(b) Hydrazine luminescence additives are required for both water-based and dry chemical current inventory fire extinguishing agents.

1. The hydrazine luminescence additive for water-based fire extinguishing agents will be compatible and miscible with water and AFFF. 2. The hydrazine luminescence additive for dry chemical-based fire extinguishing agents will be compatible and miscible with Sodium Bicarbonate and Potassium Bicarbonate agent formulations. 3. The hydrazine luminescence additive for dry chemical-based fire extinguishing agents will not be susceptible to moisture absorption and/or caking inside the extinguisher or hose line to produce restricted or blocked flow.

(c) The hydrazine luminescence additive for water-based agents, water and AFFF, will be added to the water component of the agent, only. It may not be added to the AFFF storage tank on USAF crash response vehicles. The required additive concentration in water to produce the specified smoke and flame coloration signatures shall be 5 percent by volume, or less.

(d) The required additive concentration in dry chemical extinguishers to produce the specified smoke and flame coloration signatures shall be 5 percent by weight, or less.

(e) The hydrazine luminescence additive will produce the specified smoke density and flame intensity characteristics throughout the full range of operational temperatures associated with the effective application of the host agents. Required operating temperature ranges are:

1. For water: from + 34 to 140 ^{o}F. 2. For AFFF: from + 34 to 140 ^{o}F. 3. For dry chemical agents: from TBD to 140 ^{o}F.

(f) The hydrazine luminescence additive for both water-based and dry chemical agents will not produce, or cause to produce, toxic vapors while in its neat form or when mixed with water or dry chemical agent prior to its application to the hydrazine fire source.

(g) The hydrazine luminescence additive for both water-based and dry chemical agents will produce, or cause to produce, combustion products with minimum human toxicity. Hydrazine vapors and combustion products are extremely toxic. The objective is for the luminescence additive, when introduced to a hydrazine fire, to produce smoke and other combustion products that are no more toxic than the combustion products associated with the water, AFFF or dry chemical extinguishment of a hydrocarbon fuel fire (JP-4, JP-8 & AVGAS).

(2) Logistics And Readiness

(a) Operational Availability. The hydrazine luminescence additive for both water-based and dry chemical agents will have a storage shelf life of 5 years or greater.

(b) The hydrazine luminescence additives will be logistically-supportable by CCAS and VAFB base supply organizations and systems.

(c) The hydrazine luminescence additive will be premixed in crash vehicle and pumper water storage tanks, and in hand-held or wheeled dry chemical extinguishers.

(d) Application of the hydrazine luminescence additive from hydrant-supplied pumper vehicles after on-board premix supplies have been expended shall be by eductor injection from the bulk supply container into the hose stream. The eductor system shall be designed for compatibility and ease of installation considering USAF fire

vehicle apparatus and the additive's container configuration. The eductor shall inject the design proportions of the hydrazine luminescence additive (gallons/GPM) within +/- 10% of that specified.

(e) The maximum size of the hydrazine luminescence additive bulk container shall be 5 gallons for the liquid agent additive and 50 pounds for the dry chemical agent additive.

(f) The hydrazine luminescence additive will be compatible with fire fighting vehicle storage tank materials and the materials of the associated agent dispensing, hose and turret systems.

(g) The water-based hydrazine luminescence additive normally will be added to crash vehicle or pumper on-board water storage tanks only after the notification of a hydrazine fire incident has been received by the fire department.

1 Fire chiefs will establish local policies and procedures for adding the additive chemical via field-filling operations directly from bulk supply containers (5 gallons or less). CCAS and VAFB fire chiefs may choose to premix the hydrazine luminescence additive in one or more fire fighting vehicles. 2 However, any use of the vehicle's water supply for routine turret training or tank maintenance will result in the loss of the additive. Such losses will require makeup additive to be placed in the storage tank. 3 Bench stock provisioning must be adjusted to account for these potential losses, if premixed vehicles are maintained.

(h) The container system for the hydrazine luminescence additive will include provisions for rapid field-filling of fire vehicle on-board water tanks under operational fire fighting conditions. Each container shall include a filling spout that can be rapidly attached to the main access port and an air vent port with removable cap. Hydrazine fire luminescence additive containers will be similar in design to portable, commercial 10-gallon gasoline tanks with built-in handles and telescoping or internally-stored pouring spouts and vent caps.

4. False-Alarm Immune Hydrazine Flame Detection System

a. Basis Of Operational Requirement.

(1) CCAS and VAFB technicians are involved in several hazardous processes where reliable and rapid detection of hydrazine fires will be essential in preventing

serious injury or death, and the potential for significant facility and environmental damage. These include:

(a) Loading/unloading 2,500 - 5,000 gallon mobile tankers at bulk storage facilities.

(b) Hydrazine transfers from mobile tankers or 55-gallon drums to specialized propellant containers for payload fueling.

(c) Maintenance of mobile propellant tankers and specialized satellite fueling containers.

(d) Maintenance of fixed storage tanks, transfer, and distribution systems at central bulk storage sites and at launch complex ready storage facilities.

(e) Propellant fuel (A-50) off-load at Titan IV ready storage sites.

(f) Titan IV Stage I & II A-50 fueling from on-site ready storage tanks. Delta Stage II launch vehicle A-50 fueling operations from 2,500 gallon KSC mobile tanker trailers (CCAS) and/or a Delta fuel trailer (VAFB).

(g) Satellite fueling operations in ground-level or launch tower clean room facilities and Centaur fueling in launch tower clean rooms.

(2) Fires fueled by Anhydrous Hydrazine and its derivatives are virtually smokeless and emit little or no visible radiation.

(a) Technicians involved in hypergolic propellant fuel operations wear fully-encapsulated protective ensembles. These include vision-restricting helmets and face plates.

(b) Because of the near-invisible nature of hydrazine flames and limited fields of vision, these personnel have extreme difficulties in identifying the location and size of a hydrazine fire, its rate of growth, and direction of spread.

(c) In a past hydrazine fire incident at CCAS during a propellant container maintenance operation, technician proximity to a hydrazine fire remain undetected until a very dangerous secondary effect was recognized - the melting of the individual's protective ensemble components.

(d) In such cases, these very dangerous conditions can lead to ineffective use of portable fire extinguishers, delayed or ineffective emergency

actions and evacuation to include system shutdown and sounding alarms, as well as technician injury or death.

(3) CCAS and VAFB facilities and processes with hydrazine fire hazards urgently need an automatic detection system that can reliably detect hydrazine and hydrazine derivative flames and warn personnel.

a. Current technology optical fire detectors and human "eyeballs" do not have the capability to reliably discriminate hydrazine fires.

b Additionally, UV and/or UV/IR detectors can react to non-flame false alarm stimuli, such as sunlight, welding, and various emissions from light sources. UV and UV/IR detectors have been associated with a history of false alarms and false activations of USAF hangar and aircraft shelter fire protection systems over the past several years.

b. Shortcomings of Existing Systems

(1) Background Data On Hydrazine Fires & Optical Flame Detector Reliability And Response Capabilities.

(a) Hydrazine burns at a rate that is about 10 times as fast as a hydrocarbon fuel fire. Therefore, it is more intense and spreads faster.

(b) Hydrazine fires produce little or no visible flame and smoke. This is because the carbon-based compounds that are contained in and produced by jet or automotive fuel fires are not present in hydrazines to produce black smoke and the characteristic yellow-orange flame.

(c) Hydrazine fires burn with no visible radiation. Because of this spectral quality, current UV/IR or UV-alone optical detectors cannot reliably detect the characteristic hydrazine flame. There are no commercially-available hydrazine-specific fire or flame detectors available for purchase.

(d) USAF experience with UV/IR hydrocarbon fire detectors in aircraft hangar applications has not been satisfactory.

1 Research has shown that there are many combinations of UV (sunlight, welding, etc.) and IR (motor vehicles, electric motors, lighting systems. etc.) energy at certain distances from UV/IR detector heads that fall within the specified hydrocarbon fire detection sensitivities and combine to produce false alarms. 2

sensitivities and combine to produce false alarms. 2 Numerous suppression system "false dumps" in recent years has validated this potential. Many suppression systems have been placed in the manual activation mode to prevent inadvertent agent release. 3 Since there is very little or no UV or IR energy in those spectral ranges monitored by commercial UV/IR systems, their use for hydrazine detection is not feasible.

(2) There are very little published hydrazine and hydrazine derivative flame spectral data. None is sufficient to design and/or calibrate a new hydrazine technology flame detection system.

(a) A recent Wright Laboratories Air Base Fire Protection And Crash Rescue Systems Branch (WL/FIVCF) study identified 4,450 potential sources of data on hydrazine flames using a SURVIAC search. Of this number, only one report had some partially-useable data. This was from a laboratory test analysis with little or no relevance to CCAS and VAFB field conditions where hydrazine flame detection would be required.

(b) An unpublished 1986 NASA test report provides some spectral data from very small fires at distances of only 8 and 30 centimeters. No spectral data defining fire sizes, detection ranges and other boundary conditions, such as the collateral combustion of involved materials (vegetation, vehicle & electronic components, etc.) are known to exist.

c. Capabilities Required

(1) System Performance Parameters

(a) The hydrazine flame detection system is envisioned to be a family of detection systems or a system that can be calibrated to react to flames from each of the hydrazine fuel types, and to take into account the various fire incident locations, collateral fire involvement site conditions and site-specific false alarm sources.

(b) It is not required (but is desirable) that one single hardware configuration will be able to satisfy all of the below-listed system performance parameters. This is assumed that separate, but similar systems with multiple common parts, will be required for specific site conditions where hydrazine fires can take place.

(c) Clean Room Hydrazine Flame Detection

1 The hydrazine flame detection system will identify a 6-in high anhydrous hydrazine or MMH flame produced by a laboratory burner or equivalent at a 50-ft range under interior USAF ground-level and launch tower clean room equipment, background and lighting conditions. 2 The field of view for detection shall be +/- 45 degrees as measured on a conical surface originating from the detector head central axis leading to the target flame. 3 The total conical field of view shall be not less than 90 degrees in the horizontal and vertical directions. 4 Anhydrous hydrazine and MMH are typical fuels for military and commercial satellite payloads and Centaur reaction control systems.

(d) A-50 Bulk Transfer & Storage Facility Flame Detection

1 The hydrazine flame detection system will identify a 1 square foot Aerozine-50 (A-50) pan fire at a 100-ft range under outside/exterior CCAS and VAFB fuel storage and transfer facility weather, background and lighting conditions. 2 The field of view for detection shall be +/- 45 degrees as measured on a conical surface originating from the detector head central axis leading to the target flame. 3 The total conical field of view shall be not less than 90 degrees in the horizontal and vertical directions. 4 Large quantities of A-50 are stored in bulk and transported in mobile trailers to fuel Titan and Delta launch vehicles.

(e) Hypergolic Fuel Container Maintenance Facility/Site Flame Detection

1 The hydrazine flame detection system will identify a 1 square foot Aerozine-50 (A-50), MMH, UDMH or anhydrous hydrazine pan fire at a 100-ft range under outside/exterior CCAS and VAFB fuel container maintenance facility weather, background and lighting conditions. 2 The field of view for detection shall be +/- 45 degrees as measured on a conical surface originating from the detector head central axis leading to the target flame. 3 The total conical field of view shall be not less than 90 degrees in the horizontal and vertical directions.

(f) Hydrazine flame detection system response times for both 6-in flames at 50-ft and 1-square foot pan fires at 100-feet shall be 1.0 second or less for a flame/pan fire location anywhere within the 90-degree specified field of view.

(g) Hydrazine flame detection systems shall not react/alarm to visible or radiant energy sources, such as welders, lighting systems and light bulbs, weather phenomena, motors, hot exhaust systems, cigarette lighters, flashlights or other "hot" bodies, or to any combinations of intensity and distance of such spectral emissions.

(h) Hydrazine flame detection systems shall not react/alarm to any electromagnetic energy sources associated with space launch system communications or surveillance equipment, or from any transient energy that may be associated with CCAS or VAFB space launch support operations.

(i) System detection of hydrazine flames shall result in the initiation of area visible and audible alarms/klaxons and the transmission of an alarm status message to both the CCAS/VAFB fire department and one or more TBD launch squadron command and control centers. Alarm hardware and message transmission electronics shall be detection system component subsystems. Alarm messages shall be transmitted by TBD (RF and/or hard wire) data links.

(2) Logistics and Readiness

(a) Clean Room Systems

Hydrazine flame detection systems in clean rooms shall demonstrate a system availability of 99 percent over a mission time of two years.

(b) Exterior/Outdoor Systems

Hydrazine flame detection systems protecting outdoors or other non-fully enclosed processes and/or equipment shall demonstrate a system availability of 97 percent over a mission time of two years.

d. Promising Technologies

(1) Laser-Based Detection System

(a) Research began during March 1995 to develop a laser spectrometer-based system for the detection of hydrazine that would be present in vapor releases and flames. This technical effort is being conducted by the Air Force Fire Protection Laboratory at Tyndall Air Force Base, FL. The laser spectrometer is being used to detect hydrazine by observing its transmittance spectral lines. The system would then employ a microprocessor to compare one or more transmittance peaks with known hydrazine spectral information. Initial research is investigating hydrazine

spectral signatures in the low (1.0 - 2.0 μm) and mid (2.5 - 10 μm) infrared ranges.

(b) The laser detection system would be configured to pass the beam through a volume of air that is nearby a potential hydrazine leak point. The beam would impact a target sensor, where transmittance data would be determined. Several beam - target systems can be slaved to a common detection microprocessor.

(2) Ceramic-Metallic (CerMet) Electro-Catalytic Gas (ECG) Microsensor

(a) This detection system is under development by Argonne National Laboratory's Energy Systems Division. It identifies the individual gases in a gas mixture by their electrical signatures. This is made possible by an innovative combination of CerMet materials, cyclic voltametry, and neural network signal processing. The sensor is small, 2-mm by 3-mm, and rugged.

(b) Current testing indicates that the sensors are capable of both early fire detection by the identification of the source chemical and the combustion products. A Principal Investigator at the Argonne Laboratory indicates that the system should be fully capable of detecting hydrazines and their combustion products.

(c) The cyclic voltametry technique applies a wide range of voltages to the sensor unit. Each gas in contact with the sensor reacts at a characteristic voltage. The system measures the resulting voltage-current signatures. The neural network is trained to recognize the characteristic signatures of the different gases expected to be in the sample population. Multiple sample point detectors are feasible, and would employ a microprocessor for polling, character recognition, and alarm signal processing tasks.

(d) Detection system costs are to be determined (TBD). The sensor and micro-controller chip cost about $2.00 each. The neural network processor costs for hypergolic propellant leak detection are TBD. Multiple-point sampling system manufacturing costs are TBD, but are expected to be under $1,000.

(3) Dual-Channel Infrared (IR) Hydrazine Flame Optical Detection System

(a) During the period February - March 1995, the Hughes Santa Barbara Research Center (SBRC) conducted 23 hydrazine (N_2H_4) pan fire tests. Fire sizes ranges from 10- to 44-square inches. Durations were approximately 10-seconds. The objective was to determine

the near- and far-infrared (IR) radiometric and dynamic properties of hydrazine flames.

(b) The radiometric data collected in these tests quantified the IR radiation levels of hydrazine in 14 spectral bands that are used in Hughes Santa Barbara Research Center's fire sensing product lines. SBRC concludes that hydrazine fires are detectable with IR optical sensors similar to their *Dual Spectrum Fire Sensors* currently being produced for detecting low luminosity combustibles, such as methanol, and H_2O_2.

5. Optimum Hypergolic Propellant Fire Fighting Agent

a. Basis Of Operational Requirement

(1) CCAS and VAFB fire department emergency response operations to hydrazine fuel or nitrogen tetroxide oxidizer release incidents or accidents can involve exposure to the combined flame and highly toxic liquids and vapor effects of these hypergolic propellants.

(2) CCAS and VAFB fire fighters urgently need an effective fire fighting agent to combat hydrazine and N_2O_4-enriched fires.

(3) Current fire fighting agents are water, aqueous film-forming foam (AFFF) and dry chemical (potassium or sodium bicarbonate). These agents are minimally effective against hypergolic propellant fires.

(4) More effective agents are an immediate requirement, since CCAS launch operations are projected to continue to increase over the next several years. These operations will result in increases of the frequency of hypergolic propellant transportation, transfer and use in launch vehicles and payloads. In turn, these hazardous operations will increase the overall probability of an accidental release with the potential for a fire situation to result.

(5) The fire departments at CCAS and VAFB require fire fighting agent performance information for optimum fire extinguishment and vapor suppression performance against hypergolic fuel and oxidizer-enriched fire threats. The requirement is to test available, off-the-shelf firefighting agents and chemicals with known fire extinguishment properties to determine their relative effectiveness in hydrazine fire extinguishment and hypergolic (hydrazines and nitrogen tetroxide) propellant vapor suppression.

(1) There are very sparse data on fire extinguishing agents and fire suppression techniques for hydrazine-family fires. This is because of the toxic and explosive threats of handling the materials, and the environmental restrictions governing their release to air, water and/or ground. Most references date back to the 1960's and were prepared to support the early Titan ICBM program.

(2) The CCAS and VAFB fire departments are equipped to fight hydrazine fires with crash vehicles and pumpers. The crash vehicles carry from 1,000 to 3,000 gallons of water/Aqueous Film-Forming Foam (AFFF) on board. Pumpers may carry 500 gallons of water and normally rely on hydrant connections to provide hose streams for fire extinguishment.

(3) Initial fire department response to a CCAS or VAFB hydrazine fire incident will, normally, rely on AFFF application by mobile crash vehicles, until hydrant-fed hand lines can be established. Then joint AFFF-water application can be considered by the on-scene senior fire officer. During the initial minutes of the response, the sole fire fighting capability will be the agent contained in the crash vehicle on-board tanks (1,000 - 3,000 gallons). Crash vehicle turret application rates are from 500 to 750 gallons per minute (GPM).

(4) Therefore, only a very few minutes of fire extinguishment time are available early-on for agent application on the fire. As has been previously discussed, both water and AFFF are minimally effective against hydrazine and oxidizer-enriched fires using currently-understood formulations and application rates.

(5) Hydrazine Fire Response Scenario

Combining the factors described in the previous subparagraphs, above, the following scenario results to depict the significant shortcomings of the existing system:

(a) Fire fighters responding to a hydrazine or hydrazine derivative fire will have to deal with an almost invisible fire that produces little or no smoke. They will have extreme difficulty in determining where the fire boundaries are, the total fire size and the rate of fire spread.

(b) Unless there is an eyewitness account, it will be very difficult to pinpoint the source of the released fuel and the flow mechanism, such as gravity-fed or pressurized leaks.

(c) Application of AFFF from initial response vehicles may be very ineffective, since target range and position will be very difficult to judge without visual fire signatures. Significant agent quantities may be wasted.

(d) Once on-board fire fighting agent is expended, vehicles must return to a water source for resupply, or must be connected to a fire hydrant, which may or may not be available. Crash vehicle AFFF supplies also must be replenished.

(e) During delays in agent application, reignition from hot metal surfaces or fire burn-back from foam decay can occur, or secondary fires involving collateral materials, vehicles or facilities may be ignited by the hydrazine fire. "Invisible" pockets of hydrazine fires will continue to burn until permanently extinguished or until the fuel source is depleted.

(f) Fire fighters on foot will be placed in additional danger, since they will not enjoy crash vehicle insulating safety and escape speed. Without full knockdown or extinguishment capability for large fires, and without the smoke or flame coloration danger signals, fire fighters may impinge on the fire surface before they realize its location. The danger is compounded, since the fire fighters will not be aware of fire spread direction or rate caused by wind conditions or fuel flow.

(g) Rescue attempts will be similarly dangerous. Incomplete or partial extinguishment can leave several pocket fires in the path of rescue personnel. These will also be virtually invisible if hydrazines are involved. Fire fighters can unexpectedly enter a fire area they did not know was there on their way to or from a rescue site with or without a rescue victim in tow. Because of the usually windy conditions associated with the California and Florida coastal locations of USAF launch sites, such a situation would be extremely dangerous for larger fires in the 100 - 400 gallon or larger range.

(h) Summary

1 CCAS and VAFB fire fighters, today, must fight a hypergolic propellant fires using ineffective inventory fire fighting agents. This places the

fire fighter in increased jeopardy, and significantly increases the fire loss risk to launch site facilities and, possibly, the launch vehicle and payload systems.

2 Propellant fire consequences will depend on the location of the release point relative to launch systems or facilities, the speed and accuracy of fire identification and fire department response, and the effectiveness of fire fighting agents when applied by fire fighters in vehicles and at the end of hose lines.

c. Capabilities Required

(1) General

(a) Candidate agents are water, aqueous film-forming foams (AFFF), acrylic and protein-based foams, dry chemicals and gel-encapsulated dry powders. Required data includes optimum agent stream flow rates, application techniques, proportioning ratios and life cycle considerations (cost, availability, shelf life and new/modified dispensing equipment requirements).

(b) The end product will include technical documentation sufficient to permit the development of tactics and training for the optimum use of this agent or agents by the CCAS and VAFB fire departments.

(c) Increased hypergolic propellant fire extinguishment capability is the dominant performance parameter to be developed and fielded. Vapor suppression is a desired, but not mandatory capability. Since foam-water mixtures are effective fire fighting agents for hydrocarbon fires, it is anticipated they may be effective against hypergols. By their physical nature, foams also have some capabilities to blanket and suppress toxic liquid spill vapors. To account for this possibility, system performance parameters and the Requirements Correlation Matrix (RCM) for the required agent will include desirable vapor suppression characteristics.

(d) On the other hand, following the test and evaluation of the candidate agents listed above, the optimum fire fighting agent for hypergolic propellant fires may be a dry chemical agent that exhibits no vapor suppression capability. In this possibility, CCAS and VAFB fire departments will have to assess the benefits of acquiring and supporting two separate agents for hypergol emergency response: one for fire extinguishment and one for toxic vapor suppression.

(2) System Performance Parameters

(a) The hypergolic propellant fire fighting agent or agents are intended for use in controlling and extinguishing fires fueled by hydrazine or its methyl derivatives.

(b) The hypergolic propellant fire fighting agent or agents are intended for use in controlling and extinguishing NFPA Class A and Class B fires in which combustion is supported by nitrogen tetroxide.

(c) It is desirable that the hypergolic propellant fire fighting agent or agents be effective in controlling the toxic vapor hazard from releases of hypergolic propellants: hydrazine, its derivatives, and nitrogen tetroxide.

(d) The agent application time to extinguishment for a 100 square foot hypergolic fuel pool fire shall be 15 seconds.

(e) The agent application time to extinguishment for a 100 square foot hypergolic oxidizer-enriched hydrocarbon fuel pool fire shall be 15 seconds.

(f) The burnback time of a foam cover agent shall be 5 minutes.

(g) The post-fire or no fire vapor-securing capability of a foam cover agent shall be 1 ppm for hydrazine fuels and 10 ppm for nitrogen tetroxide.

(h) The minimum foam expansion ratio of a foam cover agent shall be 200.

(i) The minimum foam 25% drainage time of a foam cover agent shall be 4 minutes.

(j) The minimum foam 50% collapse time of a foam cover agent shall be 30 minutes.

(k) A foam cover agent shall pass the wand test specified in UL 162, “Standard For Foam Equipment and Liquid Concentrates”.

(l) Hypergolic fire extinguishing agents may be water-based or a dry chemical current inventory fire extinguishing agents with or without hypergolic propellant fire suppression performance enhancement additives.

1 Water-based fire extinguishing agents and foams will be compatible with current inventory fire department vehicle agent storage and delivery components and equipment. 2 Hypergolic fire extinguishment performance additives for dry chemical-based fire extinguishing agents will be compatible and miscible with Sodium Bicarbonate and Potassium Bicarbonate agent formulations. 3 Hypergolic fire extinguishment performance additives for dry chemical-based fire extinguishing agents will not be susceptible to moisture absorption and/or caking inside the extinguisher or hose line to produce restricted or blocked flow.

(m) The hypergolic fire and vapor suppression agents or agent additives for both water-based and dry chemical agents will not produce, or cause to produce, toxic vapors while in their neat form or when mixed with water or dry chemical agent prior to its application to the hypergolic fire source.

(n) Should an effective hypergolic fire fighting agent or foam require the development and purchase of an agent/foam storage and distribution system, the following are required:

1 The system shall be mobile/towable by a 3/4 ton pickup truck. 2 The total pre-dispensed agent storage capacity shall be 500 gallons for a one-component agent. For a two-component agent, the storage capacity of each component shall be 250 gallons.

(o) Hypergolic fire fighting agents, foams and/or additives will produce the specified fire extinguishment and/or vapor suppression characteristics throughout the full range of operational temperatures associated with the effective application of the host agents. Required operating temperature ranges are:

1 For water-based agents: from + 34 to 140 $^{\circ}$F. 2 For dry chemical agents: from TBD to 140 $^{\circ}$F.

(2) Logistics and Readiness

(a) A non-fire department inventory portable foam-dispensing system may require development and fielding to apply hypergolic fire or vapor suppression foam that cannot be dispensed though existing CCAS/VAFB fire department crash vehicles.

(b) A preliminary concept of operations for a new mobile foam suppression system (if required) would be to pre-position one or several units at each fuel and oxidizer bulk storage area at CCAS and VAFB. Another two

units would be pre-positioned inside each Titan launch complex: one at the Fuel Handling Area, and one at the Oxidizer Handling Area. These standby units would be charged and ready for operation by propellant transfer and/or fire department first responders. Several roving units would be available at each fire station on CCAS and VAFB to cover emergency response to spills or fires from standby or fall-back positions during dynamic propellant transfer operations.

(c) Otherwise, AFFF or an enhanced foam formulation compatible with existing crash vehicles would be stored on board, as is currently done for AFFF.

(d) Hypergolic propellant fire fighting and/or vapor suppression agents or agent additives are expected to decrease fire extinguishment time, increase burnback resistance and decrease vapor emissions from hypergolic propellant fires and/or liquid chemical pools.

6. Launch Tower Emergency Escape Chute

a. Basis Of Operational Requirement

(1) Space vehicle launch and payload processing facilities at CCAS and VAFB support all major United States Air Force (USAF) and commercial satellite space launch operations. These facilities support systems and processes that involve the storage and transfer of highly flammable, explosive and toxic hydrazine fuels.

(2) Universal Environmental Shelters (UES) are constructed on the higher levels of launch pad Mobile Service Towers (MST). They encircle the upper stages and payloads to provide protected access for final servicing, checkout, and propellant loading. Clean rooms are provided where access to payloads and/or fuel transfer ports are required. These facilities are located at elevations over 100 feet above ground level.

(3) Typical hazardous operations that are conducted in elevated launch tower clean room facilities include satellite and Centaur upper stage reaction control system (RCS) fueling. For monopropellant payloads and boosters, anhydrous or monomeythyl hydrazine is transferred from 55-gallon drums, NASA drain containers or payload specific GSE to the on-board storage tanks via propellant transfer units (PTUs) and conditioning panels. Fuel capacities range from 40 gallons for the Centaur to several hundred gallons for large satellite systems. Some payloads may include a dual-propellant RCS. In this case, a separate oxidizer (nitrogen tetroxide) loading operation is conducted inside the clean room.

(4) Hazardous clean room propellant transfer operations are conducted by a small cadre of engineers, technicians and safety professionals. Typically, no more than six personnel are required to conduct a fueling task. Since hypergolic propellants are extremely toxic chemicals, all personnel inside the clean room during fueling or defueling operations are protected by NASA-developed Self-Contained Atmospheric Protective Ensembles (SCAPE). Breathing air for personnel in SCAPE is provided by a tether from a central source. Emergency air supplies are provided by portable bottles that are carried by each individual.

(5) Propellant transfer operations are conducted following strict procedures and protocols to minimize the potential for accidental release. Fuel transfer lines are wrapped in shrouds and transfer equipment is set in stainless steel drip pans to contain incidental vapor or liquid releases. Emergency ventilation systems and air aspirators are available to prevent larger releases from reaching an explosive vapor concentration level (lower explosive limit). Portable vapor detection systems are used to monitor potential leak locations and provide an early indication of an equipment malfunction or material failure.

b. Shortcomings Of Existing Systems

(1) Depending on the launch tower involved (Atlas, Delta & Titan) and the base location (Cape Canaveral & Vandenberg), emergency egress will be limited to one or two open stairwells located on the exterior of the MST superstructure. Escaping personnel will be attired in SCAPE and must carry their own emergency air supply bottles. Injured personnel and their air supplies must be litter-carried or fireman-carried by another member of the clean room crew to ground level. The requirement to carry both the injured and their air supplies, plus the rescuer's air supply bottle(s), greatly complicates the rescue scenario.

(2) Escaping personnel must exit the clean room threat area, locate the nearest stairwell to lower elevations and descend a vertical distance that may exceed 100 feet. This must be done under emergency/panic conditions, with a limited air supply, and with the possibility of transporting casualties. Fire department rescue personnel are located at fallback locations. Emergency assistance will not be available to the clean room crew until after they reach the ground level and evacuate the launch tower area.

c. Capabilities Required

(1) Escape Chute Concept Of Operations

(a) Personnel working inside CCAS and VAFB clean rooms or who may be working in the proximity of other hazardous systems/operations require a direct, rapid, emergency egress system from the launch tower elevation where the hazardous operation takes to the ground elevation, below.

(b) The most economical emergency egress system consists of a mobile/portable, lightweight escape chute, Figure XI-5. Two off-the-shelf systems are depicted: the EVAC Personal Rescue Chute and the Baker Life Chute.

(c) An escape chute system would be deployed only during selected hazardous operations. It would be connected to the MST superstructure by means of stainless steel collar or panic escape platform.

(d) The escape chute would extend from the MST connection system to the ground below. It would be positioned to provide the required lateral clearance from the launch tower superstructure and to avoid any facilities or equipment that may be in the egress area. Anchorage at the ground-level egress point may or may not be required.

(e) One or more escape chutes would be installed, depending on the threat level, the configuration of the clean room and launch tower superstructure, and range safety directives.

(f) Escaping personnel would enter the escape chute system at the hazard elevation and exit chute at ground level without any outside assistance at either level. The crew making the emergency evacuation may assist each other at the top or ground level locations, as required. However, there will be no additional personnel standing by at either chute location to provide entry or egress assistance.

(g) Each escape chute system would be protected by a separate, reflectorized outer cover to provide radiant and conductive heat protection from clean room or other fire threats. The reflectorized cover is needed only for those elevations where fire threats may occur, and need not extend the full length of the fully operational chute.

(h) Upon completion of the hazardous operation or the emergency egress, the escape chute system (s) would be removed from the launch tower, cleaned and stored, and otherwise processed for re-use.

(2) System Performance Parameters

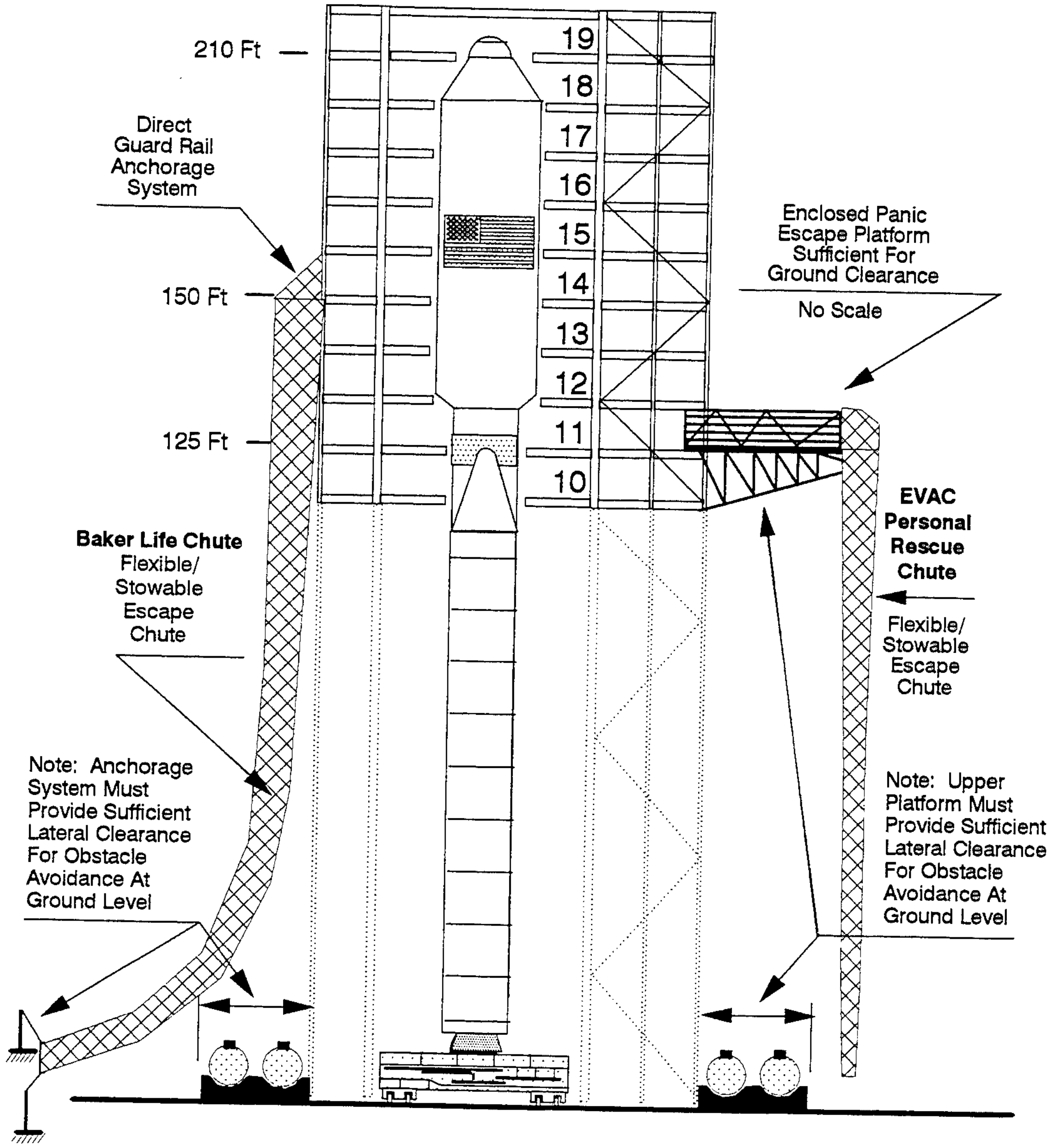
(a) The escape chute system shall be of sufficient diameter throughout its length to accommodate persons attired in NASA-developed Self-Contained Atmospheric Protective Ensembles (SCAPE). The minimum required diameter of the upper anchor ring for entry into the escape chute tube at top of the system shall be TBD feet. Commercially available systems have topside anchor systems in the 2 to 3-foot diameter range. Personnel in SCAPE with portable air bottles may require a larger opening. The minimum required diameter of the lower anchor ring for egress from the escape chute tube at ground level shall be TBD feet.

(b) The escape chute web/fabric sections shall be constructed of high tensile strength, non-corrosive material (s) that are resistant to Atlantic and Pacific coast salt water spray, wind, UV radiation, temperature and other weather conditions. The expected maximum simultaneous evacuee loading that the chute must safely support is 10 personnel attired in SCAPE with a total weight of 2,500 pounds.

(c) The reflectorized outer cover shall consist of a NFPA-compliant, heat-resistant, reflective material, such as that produced by the Gentex Corporation. Such material shall be resistant to Atlantic and Pacific coast salt water spray, wind, UV radiation, temperature and other weather conditions, to the maximum extent possible.

(d) The escape chute upper anchor system shall be capable of being secured to CCAS and VAFB launch tower superstructure steel members at various locations. The design of the upper anchor section, panic platform (if required) and connections to the outer edge of the launch tower shall provide a continuous enclosed area to safely enter the chute. The entry system design shall account for the panic evacuation of personnel in cumbersome SCAPE suits with limited visibility and dexterity.

(e) The escape chute assembly must be capable of being positioned at the upper level hazard area and anchored at the ground level (if required) to provide the required lateral clearance for effective use of the chute and to avoid ground-level obstacles in the exit area.



Operational Concept

Panic escape platforms or chute connection collars are attached to the MST at levels where Centaur &/or payload propellant transfer hazardous operations take place. For fire and/or explosive vapor threats, personnel would exit the clean room (or other) area and use the escape chute emergency egress system to the reach ground level without assistance. Escape chutes would be deployed only during hazardous operations. They would be stored in weather-tight mobile containers at each level of installation.

Figure XI-5. Launch Tower Emergency Escape Chute Configuration And Operational Concept.

(f) The escape chute system must be capable of providing emergency egress from launch tower hazard areas without assistance from additional/other personnel who are not a part of the hazardous operation crew. Assistance shall not be provided at either the elevated chute entry level or at the ground-level chute egress point.

(g) The maximum escape chute length shall be TBD feet (Approximately 200-ft). The maximum length of the reflectorized outer cover shall be TBD (Approximately 100 feet).

(3) Logistics And Readiness

(a) The escape chute system shall be designed for ease of installation, deployment and retraction and reuse.

(b) The escape chute system shall include a wheeled, weather-tight storage container.

(c) All escape chute and storage container metal components shall be manufactured of stainless steel.

(d) The escape chute system shall include manufacturer's requirements for cleaning, maintenance, repair and replacement of components due to wear and tear, as well as for exposure to temperature and weather conditions. A detailed installation, deployment, retraction and maintenance manual also shall be provided.

7. OSHA-Compliant Contractor HAZMAT Emergency Response Plan

a. Basis Of Operational Requirement

(1) Emergency Response Provisions Of HQ AFSPC/SE/CE Memo Dated 12 May 1994, *Interim Policy For Fire Protection Systems In Launch Tower Satellite Clean Rooms*, are as follows:

(a) Command policy is to apply life safety standards and fire protection systems according to the following priority sequence: *first protect people, then the payload, and, finally, the facility*.

(b) Personnel protection is provided by fire/mishap prevention training, egress training, hazardous/toxic material detectors and alarms, protected egress, emergency air purge systems, protective equipment and hazardous operation procedures reviews.

(2) Because of the unique hazards associated with the CCAS mission, the Air Force and its civilian contractor employers must provide special or additional safety features, procedures, training and other safeguards in facilities and during processing operations to ensure compliance with current Federal Law regarding fire protection, worker and workplace safety, and HAZMAT emergency response.

(a) Employers of military, Air Force civilian and contractor personnel who participate in the emergency response to accidental releases and fires involving highly toxic hypergolic fuels and/or other hazardous materials (HAZMAT) used in CCAS workplaces must ensure personnel are equipped and trained to the mandatory requirements specified in OSHA 29 CFR 1910.120(q), *Emergency Response To Hazardous Substance Releases.*

(b) Employers of personnel who simply evacuate the area of an accidental HAZMAT release must ensure personnel are trained to respond in accordance with OSHA 29 CFR 1910.38 (a), *Employee Emergency Action Plan.*

b. Shortcomings Of Existing Systems

(1) Air Force Instruction (AFI) 32-4002, *Hazardous Material Emergency Planning And Response Compliance, 9 May 1994,* defines the minimum requirements for base-level HAZMAT emergency response planning and response compliance with all Federal regulations regarding worker safety and the reporting and response to HAZMAT and petroleum pollutant release incidents. This AFI is written from the perspective of a "typical" USAF installation consisting of a flying and/or strategic launch mission and staffed with military personnel and Civil Service employees. On such a base, a mix of military and government employees staff the base disaster response force (DRF). Additionally, the base fire department HAZMAT Response Team is staffed by government employees.

(2) CCAS is very different. This base, essentially, is staffed by a small cadre of USAF military program/operations managers and support staff. Actual base, launch vehicle and payload support activities are conducted by a large group of contractor organizations.

(a) Hypergolic propellant transfer operations, to include launch vehicle and payload fueling, are conducted by contractor personnel.

(b) In some cases, NASA contractors are involved in hypergolic transfer operations on CCAS in support of both NASA and USAF programs.

(c) The CCAS fire department, including its HAZMAT Response Team, is contractor-provided, as are many other elements of the DRF.

(3) VAFB also has multiple support contractors for launch operations, payload processing and propellants storage management. However, the VAFB fire department and most other base operations are by standard, military - Civil Service organizations.

(4) Contractor employees who conduct propellant loading and container maintenance operations and take part in any way in the response to an accidental release or spill incident (find, fix, cleanup, decon, etc.) are, by Law, emergency responders, and must be trained and equipped according to the OSHA HAZMAT emergency response standard. AFI 32-4002 does not specifically address the HAZMAT planning and response issues generated by this very unique military-contractor partnership in the space lift operations arena.

(5) OSHA 29 CFR 1910.120(q), *Emergency Response To Hazardous Substance Releases*, is referenced in AFI 32-4002, and requires specific policies, plans and procedures for all employers of personnel who participate in a HAZMAT emergency response.

(a) Air Force plans and procedures that are promulgated to cover all hazardous operations on CCAS and VAFB should be consistent with each of the civilian contractor plans and procedures that are promulgated to protect individual employees.

(b) Since employees from several civilian firms and military personnel may participate in a single hazardous operation, consistent plans and procedures between these organizations also are essential.

(c) Each emergency responder must be trained according to the OSHA standard, and must attend refresher training or demonstrate competency at least annually. Therefore, joint, consistent Air Force-contractor HAZMAT emergency response exercises are suggested. The nine hypergolic propellant-related accidental release scenarios defined in Section IX are suggested as the basis for such exercises.

c. Capabilities Required

(1) CCAS and VAFB HAZMAT Emergency Response Plans must be specifically tailored to the unique hazardous operations that involve hypergolic propellants.

(2) OSHA-compliant HAZMAT Emergency Response Plans are required for both military and civilian contractor employers of personnel who participate in the emergency response to an accidental hypergolic chemical release on CCAS or VAFB. These plans also must detail policies and emergency actions for personnel who work in the vicinity of a potential accidental release site, and who must evacuate their work place, if an accidental release occurs. Specifically:

(a) Military and civilian contractor employers of personnel who immediately evacuate a launch tower clean room following an accidental hypergolic propellant release incident shall comply with OSHA 29 CFR 1910.38 (a), *Employee Emergency Action Plan*.

(b) Military and civilian contractor employers of personnel who supervise, direct or otherwise participate in the identification, termination or clean-up of an accidental hypergolic propellant release inside a launch tower clean room shall comply with OSHA 29 CFR 1910.120 (q), *Emergency Response To Hazardous Substance Releases*.

(c) Coordinated military and civilian contractor plans and training shall be implemented to ensure all clean room emergency response participants are certified to Air Force and OSHA standards, and that an integrated Incident Command System is established to direct joint military-contractor emergency actions according to OSHA law.

(3) The Incident Command Systems (ICSs) that are empowered to execute these plans, also must be specifically tailored to the unique operational requirements at CCAS and VAFB that involve hypergolic propellants.

(4) CCAS and VAFB plans and Incident Command Systems must be tailored to the joint responsibilities of the military contractor responsibilities associated with hazardous operations and emergency response.

SECTION XII

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

1. Objective

The objective of this analysis was to determine fire protection research and development (R&D) requirements that are unique to the fire departments operating at Cape Canaveral Air Station (CCAS), Florida, and Vandenberg Air Force Base (VAFB), California. Operational uniqueness was established by virtue of the mission requirement for these fire departments to conduct fire suppression, rescue and/or hazardous material (HAZMAT) emergency response operations involving the extremely toxic and explosive hypergolic propellants used in space lift vehicles and satellites.

2. Scope

This research quantifies fire protection R&D requirements generated by the CCAS and VAFB fire department missions to provide suppression, rescue and fire prevention in support of United States Air Force (USAF), Department of Defense (DoD) and commercial satellite launch operations. The final products are a technical report, five (5) draft Operational Requirements Documents (ORDs), a draft purchase description (PD), and a draft HAZMAT Emergency Response Plan for civilian contractors.

3. Technical Approach

a. The technical approach employed an operational hazard analysis of space launch and payload processing facilities and operations at the CCAS and VAFB launch sites to determine fire department emergency response environments and requirements. The mechanisms and estimated quantities of accidental releases of highly flammable, explosive and toxic hypergolic propellants were quantified.

b. Nine fundamental hazard scenarios were developed to characterize propellant release circumstances that would result in CCAS or VAFB fire department fire fighting or hazardous material emergency response. For each scenario, the release mechanisms, the release quantities, and the consequences of the release were estimated.

c. On 26 April 1994, a panel of expert fire fighters was convened at CCAS to validate the hazard analysis results and to determine if new fire department operational requirements were needed to effectively conduct fire, rescue and HAZMAT response operations. The panel was hosted by the 45th Space Wing Fire Chief, and consisted of

the CCAS and VAFB Fire Chiefs, their Assistant Chiefs for Fire Prevention, the HQ Space Command Fire Protection Liaison Officer (HQ AFSPC/CEORF), and the HQ Space Command Chief of Readiness Requirements (HQ AFSPC/CEOR).

d. The expert panel identified the core fire department operational capabilities that are needed for effective fire suppression and rescue emergency response operations at CCAS and VAFB. Inventory fire department agents, vehicles and fire prevention systems were then mapped to the identified core required capabilities, and shortfalls in capability, if any, were defined.

e. Similarly, facility-specific hazard conditions were evaluated. Required capabilities for hypergolic vapor and flame detection, launch tower clean room emergency egress, and emergency response planning for clean room hazardous operations were evaluated.

f. Where required capabilities exceeded existing capabilities, formal statements of operational requirement were established. R&D requirements were established for increases in capability that are not available from inventory assets or off-the-shelf technologies.

B. CONCLUSIONS

1. The probability of an accidental release of hypergolic chemicals at CCAS or VAFB is low. This low release incidence estimate is founded on the space launch community's strictly-enforced system safety programs, the use of strictly-controlled propellant transfer operations procedures, and effective maintenance of propellant storage and handling facilities and equipment.

2. Very large quantities of hydrazines and nitrogen tetroxide are stored and handled at both CCAS and VAFB. The fire departments must be provisioned and trained to conduct safe and effective fire suppression and rescue operations in the highly toxic vapor atmospheres, in case there is an accidental release of these hypergolic propellants.

a. Propellant dynamic transfer operations span a wide range of quantities and flow rates.

(1) Fueling or defueling operations for the Titan IV launch vehicle, for example, total 44,672 gallons of hypergolic propellants at flow rates between 100 and 200 gpm.

(2) Payload thrust and reaction control systems, conversely, require fuel to be loaded in 20 to 100 gallon quantities. Flow rates for these operations, normally, do not exceed 0.5 to 1.0 gpm.

b. Fire department response to releases of hypergolic propellants is defined by nine fundamental accident scenarios. Unplanned propellant releases occur during dynamic transfer and sampling operations, and as a result of impact damage sustained during container maintenance, handling and transportation accidents.

c. Credible release quantities of hydrazine fuels or oxidizer that result from accidents, transfer system material failures or human error range from 0.1 to 400 gallons.

d. A catastrophic propellant release has a very low probability of occurrence, and is not a credible basis for determining fire department operational requirements.

(1) Under such circumstances, the estimated fire areas are very large, and inventory fire department manpower and equipment resources for extinguishment would be ineffective.

(2) The fire department primary roles would be to minimize collateral damage and fire spread, and to conduct search and rescue.

(3) The required increases in operational capabilities needed for these roles were identified in the analysis for effective fire department response to a 400-gallon propellant fire. Thus, fire department capabilities for catastrophic scenario collateral support are proportionally increased.

3. CCAS and VAFB fire fighters cannot safely conduct suppression and/or rescue operations in the vicinity of the toxic vapors and combustion products associated a hypergolic propellant vapor release and fire.

a. Current fire fighter reflectorized ensembles do not provide the full encapsulation required by OSHA for protection against propellant toxic vapors.

b. Inventory fully-encapsulated fire fighter HAZMAT suits will melt in the proximity of a fire.

4. Many different civilian contractor companies are involved in hypergolic propellant transfer operations or have employees who may be nearby an accidental release. Therefore, consistent OSHA-compliant hazardous chemical release emergency response plans, procedures and training are required to ensure the life safety of personnel.

5. CCAS and VAFB fire fighters urgently need live fire-validated extinguishing agent performance data to plan for safe and effective hydrazine and N_2O_4-enriched fire fighting and rescue operations.

6. Personnel working inside elevated launch tower clean rooms or who may be working on launch towers in the proximity of other hazardous systems/operations require a direct, rapid, emergency egress system from the elevation where the hazardous operation takes place to the ground, below.

7. CCAS and VAFB operational requirements for increased capabilities to deal more effectively with accidental releases of hypergolic propellants require formal documentation. Therefore, draft requirements documents were prepared and submitted to HQ AFSPC, as follows:

a. A draft Operational Requirements Document (ORD) was prepared to enable the development, testing and acquisition of each increased fire protection capability or technology requiring R&D. Required capabilities were prioritized by the AFSPC fire protection community, as follows:

(1) A combined fire fighter/HAZMAT protective ensemble with body cooling for sustained fire fighting and rescue operations in a dual threat hypergolic propellant fire and toxic vapor environment.

(2) Hydrazine vapor detection capable of incipient leak identification in the 1 - 25 parts per million (ppm) concentration range.

(3) An additive to water, foam and dry chemical fire extinguishing agents that produces a visible flame and/or smoke when applied to a hydrazine fire.

(4) False-alarm immune hydrazine flame detection.

(5) Optimization of fire extinguishment parameters and capabilities for current technology agents, such as water, dry chemicals and foams (including acrylic-modified foams) based on large fire (400 gallons/5,000 square feet) experiments.

b. Two operational requirements that are not within current inventory capabilities, but can be obtained from off-the-shelf technologies also were validated:

(1) Life safety upgrades in MST launch tower clean room facilities, to include means of egress from high elevation hazard areas. A draft purchase description (PD)

for a portable emergency escape chute system was delivered to HQ AFSPC.

(2) OSHA-compliant, launch tower emergency response plans and procedures for civilian contractors and their employees. A draft contractor HAZMAT Emergency Response Plan was delivered to HQ AFSPC.

8. The potential benefits from the R&D technologies identified in operational requirements documents delivered under this technical effort include:

- More rapid and reliable detection of hydrazine vapor releases and fires.
- Increased life safety of personnel involved in hypergolic propellant hazardous operations and in emergency response to accidental HAZMAT releases.
- The capability to extinguish hypergolic propellant fires in a toxic vapor environment.
- A significant increase in fire fighter operational sustainability while wearing a protective ensemble.
- More effective and safer extinguishment of hypergolic propellant fires.

9. The increased capabilities and new technologies that were identified by this technical effort are immediately applicable to CCAS and VAFB fire department responsibilities and missions.

a. Flame and vapor detection technologies can be applied immediately to CCAS and VAFB propellant storage facilities and payload processing clean rooms. The chemical luminescence additive to permit the visible identification of hydrazine fires can be used immediately by the CCAS and VAFB fire departments for training and actual operations.

b. The combined fire fighter/HAZMAT protective ensemble with body cooling is applicable immediately to all Air Force, DOD, NASA, DOE and other Government personnel who require the use of fully-encapsulated equipment for toxic chemical and/or fire fighting protection.

c. Once fire fighting agent suppression effectiveness parameters for large scale hypergolic propellant fires are identified by R&D, this information can be used by CCAS and VAFB fire departments to develop tactics, procedures, apparatus and equipment for optimum fire extinguishment response to hypergolic fuel and oxidizer releases and fires.

C. RECOMMENDATIONS

1. Headquarters, Air Force Space Command should:

a. Approve the five ORDs for enhanced fire protection capabilities at space launch support facilities.

b. Submit these ORDs for Air Force-wide review and validation, according to the procedures contained in AFI 10-601, *Mission Needs and Operational Requirements Guidance and Procedures*, 31 May 1994.

c. Advocate joint sponsorship of the ORD for the combined fire fighter/HAZMAT protective ensemble with body cooling to the Combat Air Forces (CAF) and joint services.

2. The draft requirements documents prepared for non-R&D increases in fire protection capabilities should be reviewed by CCAS/VAFB commanders for potential use as enhancements to their on-going emergency response and process safety management programs. These documents are:

- The HAZMAT emergency response plan for launch tower contractor employees.
- The draft purchase description for a launch tower emergency escape chute system.

3. HQ AFSPC should exploit the technology transfer potential of identified operational requirements to enhance their potential for validation and funding.

a. Potential non-DOD users of flame and vapor detection technologies, of the chemical luminescence additive, and of optimum fire extinguishing agents include chemical producers of hydrazines and industrial fire brigades in facilities or plants that use and store hydrazines.

b. The technologies associated with the combined fire fighter/HAZMAT protective ensemble with body cooling are transferable to all fire department and commercial organizations that are involved in processes that require employees to be protected against the effects of toxic chemicals and/or fires involving HAZMATs. Fundamentally, the ensemble technologies are universally transferable, worldwide.

c. All technologies identified for enhanced fire department support of space launch operations and facilities are transferable to foreign and commercial organizations with similar hazardous processes, facilities and missions.

4. The 30th and 45th Space Wings should ensure that OSHA-compliant emergency response plans and training programs are prepared by both military and civilian employers at CCAS and VAFB. Key provisions of OSHA law are as follows:

a. Each military and civilian contractor employer of personnel involved in operations to identify, contain, terminate and clean up an accidental hypergolic propellant release must comply with the planning and training requirements of OSHA 29 CFR 1910.120 (q), *Response to accidental releases of hazardous substances*.

b. Military and civilian employers of personnel who may be in the vicinity of an accidental propellant release, and who must evacuate their workplaces, must comply with OSHA 29 CFR 1910.38 (a), *Emergency action plan*.

c. Integrated, military-civilian contractor disaster response exercises should be conducted for each of the nine accidental release scenarios identified by this technical effort. This recommendation would be in support of the annual training requirements identified in OSHA 29 CFR 1910.120 (q)(8), *Refresher training*.

d. Supporting Rationale For This Recommendation.

(1) Fire Fighter Configuration and Responsibility Following An Accidental Release Of A Hypergolic Propellant.

(a) Fire department personnel and equipment do not stand-by in the immediate area of a propellant dynamic transfer operation.

(b) For hazardous operations where fire department support is required, fire fighters are positioned at fall-back positions that can be hundreds of feet, or miles, from the hazardous operation site. The "typical" standby crew at CCAS consists of two fire fighters in a crash response vehicle that carries a foam supply and 1,000 to 1,500 gallons water.

(c) Fire fighters at fall-back positions are clothed in their structural fire fighting ensembles. Should an emergency occur, they would have to report to the on-site Incident Commander (usually the Senior Fire Officer (SFO) or the Base Commander) for emergency response taskings. Should an entry be required into the hazard area, the Incident Commander would direct the wear of three possible protective ensembles:

- The structural fire fighting ensemble with SCBA.
- The aircraft crash/fire rescue (CFR) reflectorized fire fighting ensemble with SCBA.
- The fully-encapsulated HAZMAT ensembles with SCBA.

(d) Once fully donned in protective gear, the Incident Commander would direct fire fighter entry into the hazard zone for reconnaissance, firefighting or rescue tasks. Site entry would be conducted upwind, according to on-site wind conditions.

(2) Hypergolic Propellant Emergency Response Qualifications.

(a) Fire fighters are trained in fire and vapor suppression tactics and rescue. They are not trained in propellant transfer system trouble-shooting and leak isolation.

(b) The only trained and qualified emergency response force available to the Incident Commander include:

- The uninjured civilian contractor engineers, technicians and safety representatives who were directly involved in the hazardous operation.
- Other on-site contractor personnel who possess certified competency in such operations.

These personnel would be fully protected against toxic chemical liquid and vapor threats by SCAPE at the time of the accident and during any emergency response operation.

(3) Military and Civilian Contractor Engineer/Technician Configuration and Responsibility Following An Accidental Release Of A Hypergolic Propellant.

(a) The civilian contractor and military employees who are present during propellant transfer operations are best positioned and qualified to identify and react to the conditions of the chemical release. They are fully protected against propellant toxic vapors by SCAPE. Potential emergency actions of these personnel include:

- Notifications and alarms activation.
- Activation of fire suppression and/or emergency, high-capacity, exhaust systems.
- Emergency system shut-down and release isolation.
- Suppression of small fires, if present, using hand-held extinguishers or charged hose lines.
- Use of aspirators to remove liquids from the leak site.
- Accomplishment of physical modifications to the propellant transfer system component(s) involved in the release to patch or plug breaches in hardware materials.
- Mop and sop of leaks or spills.
- Final site clean up and neutralization.

(b) Propellant transfer operations conducted by civilian contractor and military personnel where accidental releases can occur include: product sampling from container trailers and containers; propellant transfers between mobile trailers, small containers and/or bulk storage tanks; launch vehicle fueling and defueling, and clean room satellite fueling operations.

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